Chapter 5

Academic Research and Development

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Highlights

Financial Resources for Academic R&D

In 2004, U.S. academic institutions spent $42 billion on research and development. Between 1970 and 2004, average annual growth in R&D was stronger for the academic sector than for any other R&D-performing sector except the nonprofit sector.

- During this period, academic R&D rose from about 0.2% to about 0.4% of the gross domestic product.
- Academic performers are estimated to account for 54% of U.S. basic research, about 33% of total (basic plus applied) research, and 14% of all R&D estimated to have been conducted in the United States in 2004.

All reported sources of support for academic R&D—federal, industrial, state and local, and institutional—increased fairly continuously in absolute dollar terms between 1972 and 2003, even after adjusting for inflation. However, the long-term trends of a declining share of support from the federal government and an increasing share from industry showed signs of reversing at the end of this period.

- The federal government provided 62% of academic R&D expenditures in 2003, substantial growth from the 58% share of support provided in 2000. The federal share of support had been in decline since the early 1970s, when it reached a high of 69%.
- Institutions themselves contributed 19% of funds in 2003, compared with 11% in 1972.
- Industry's share of academic R&D support grew rapidly during the 1970s and 1980s, fluctuated around 7% of the total during the 1990s, and declined substantially thereafter to 5% in 2003 as a result of absolute constant dollar declines in support in 2002 and 2003.

Between 1973 and 2003, there was a substantial relative shift in the share of academic R&D funds received by different science and engineering fields. However, all gained substantially in terms of absolute dollars, even after adjusting for inflation.

- The life sciences (59% share in 2003), engineering (15% share), and the computer sciences (3% share) experienced share increases. However, the engineering share declined between 1993 and 2003.
- The physical sciences (8% share in 2003); earth, atmospheric, and ocean sciences (6% share); social sciences; and psychology (6% combined shares) had share losses.

The historical concentration of academic R&D funds among the top research universities diminished somewhat between the early 1980s and mid-1990s but has remained relatively steady since then. Academic R&D activity is also occurring in a wider set of institutions.

- The set of institutions in the group below the top 100 academic R&D institutions in funding increased their share of total academic R&D expenditures from 17% to 20% between 1983 and 2003. This was offset by a decline in the top 10 institutions' share from 20% to 17%.
- The change in the number of institutions supported occurred almost exclusively among higher education institutions classified as Carnegie comprehensive; liberal arts; 2-year community, junior, and technical; or professional and other specialized schools.

In 2003, although about $1.8 billion in current funds was spent on R&D equipment, the share of all annual R&D expenditures spent on research equipment reached a historical low.

- After reaching a high of just above 7% in 1986, the share of R&D spent on equipment declined by about one-third to 4.5% in 2003.
- About 81% of equipment expenditures were concentrated in the life sciences (45%), engineering (20%), and the physical sciences (16%).

Research-performing colleges and universities continued to expand their stock of research space in FY 2003 with the largest increase in total research space (11%) since 1988. In addition to the traditional "bricks and mortar" research infrastructure, "cyberinfrastructure" is playing an increasingly important role in the conduct of S&E research.

- Between 1988 and 2003, little changed in the distribution of research space across S&E fields.
- Although 71% of university connections to the commodity Internet (Internet1) were at the two lowest speeds, at least 6% of the connections were at 1 gigabit/second or faster.

Doctoral Scientists and Engineers in Academia

The size of the doctoral academic S&E workforce reached an estimated 258,300 in 2003 but grew more slowly than the number of S&E doctorate holders in other employment sectors. Between 1973 and 2003 in academia, full-time faculty positions increased more slowly than postdoc and other full- and part-time positions, especially at research universities.

- The academic share of all doctoral S&E employment dropped from 55% in 1973 to 45% in 2003.
- The share of full-time faculty declined from 87% in the early 1970s to 75% in 2003. Other full-time positions rose to 14% of the total, and postdoc and part-time appointments stood at 6% and 5%, respectively.

The academic doctoral labor force has been aging during the past quarter century.

- Both the mean and median age increased almost monotonically between 1973 and 2003.
- In 2003, a growing, albeit small, fraction of employment was made up of individuals age 65 or older (4%), although the share of those 70 years or older declined for the first time since the late 1980s to just below 1%.

The demographic composition of the academic doctoral labor force experienced substantial changes between 1973 and 2003.

- The number of women in academia increased more than sevenfold between 1973 and 2003, from 10,700 to an estimated 78,500, raising their share from 9% to 30%.
- Although their numbers are increasing, underrepresented minorities—blacks, Hispanics, and American Indians/Alaska Natives—remain a small percentage of the S&E doctorate holders employed in academia.
- The number and share of Asians/Pacific Islanders entering the academic S&E doctoral workforce increased substantially between 1973 and 2003.
- The relative prominence of whites, particularly white males, in the academic S&E doctoral workforce diminished between 1973 and 2003.

Foreign-born scientists and engineers constituted 23% of scientists and engineers with U.S. doctorates in academic employment in 2003. This lower bound estimate of foreign-born doctorate holders excludes doctorates from foreign institutions.

- The share of foreign-born doctorate holders was more than double that in 1973, when it stood at 11%.
- Academic employment of foreign-born doctorate holders was highest in the computer sciences and engineering (44% and 40%, respectively), followed by mathematics (33%), the physical sciences (25%), and the life sciences (22%).

As the composition of positions in the academic workforce has changed over the years, a substantial academic researcher pool has developed outside the regular faculty ranks.

- As the faculty share of the academic workforce has declined, postdocs and others in full-time nonfaculty positions have become an increasing percentage of those doing research at academic institutions. This change was especially pronounced in the 1990s.
- A long-term upward trend is evident in the number of academically employed S&E doctorate holders whose primary activity is research relative to total academic employment of S&E doctorate holders.

In most fields, the percentage of academic researchers with federal support for their work was lower in 2003 than in the late 1980s.

- Full-time faculty were less likely to receive federal support (45%) than other full-time doctoral employees (48%). Both of these groups were less frequently supported than postdocs (78%).
- For each of the three groups mentioned above (full-time faculty, other full-time employees, and postdocs) recent doctorate recipients were less likely to receive federal support than their more-established colleagues.

Outputs of S&E Research: Articles and Patents

The worldwide S&E publications output captured in *Science Citation Index* and *Social Sciences Citation Index* grew from approximately 466,000 articles in 1988 to nearly 700,000 in 2003, an increase of 50%.

- This growth was a result of more articles published per journal and an increase in the number of journals covered by these two databases.

Worldwide growth in article output between 1988 and 2003 was strongest in the European Union (EU)-15, Japan, and the East Asia-4 (China, Singapore, South Korea, and Taiwan).

- The EU-15 share of world output surpassed that of the United States in 1998, although growth in the EU-15 and also in Japan slowed starting in the mid-1990s.
- The article output of the East Asia-4 grew more than sevenfold during this period, resulting in its share of world output rising from less than 2% to 8%.

The number of U.S. scientific publications remained essentially flat between 1992 and 2003, causing the U.S. share of world article output to decline from 38% to 30% between 1988 and 2003.

- The flattening of U.S. output—199,864 articles in 1992, 211,233 articles in 2003—in the face of continuing growth of research inputs represents a trend change from several decades' growth in number of U.S. publications.

The share of publications with authors from multiple countries—an indicator of international collaboration and the globalization of science—grew worldwide and for most countries between 1988 and 2003.

- In 2003, 20% of all articles had at least one foreign author, up from 8% in 1988.

The increase in international collaboration reflects intensified collaboration among the United States, EU-15, and Japan. It also reflects greater collaboration between these S&E publishing regions and developing countries and an emerging zone of intraregional collaboration centered in East Asia.

- The share of internationally coauthored articles at least doubled in the United States, the EU-15, and Japan.
- A pattern of intraregional collaboration emerged in East Asia in the mid-1990s centered in Japan and, increasingly, in China.

The United States has the largest share of all internationally authored papers of any single country, and its researchers collaborate with counterparts in more countries than do the researchers of any other country.

- U.S.-based authors were represented in 44% of all internationally coauthored articles in 2003 and collaborated with authors in 172 of the 192 countries that had any internationally coauthored articles in 2003.
- U.S. collaboration with the rest of the world continues to increase, but its relative share of coauthorship on other countries' internationally authored articles has declined as those countries have broadened their international ties.

As measured by the share of collaborative articles, both intrainstitutional collaboration of U.S. sectors and collaboration of these sectors with the rest of the world have increased significantly.

- The share of U.S. academic articles with at least one non-U.S. address grew from 10% to 24% between 1988 and 2003. The share of U.S. academic articles with nonacademic U.S. authors increased by 6 percentage points during this period, to 30%.

The volume of citations to S&E literature grew more than 60% between 1992 and 2003.

- The growth in citations was the greatest in the same S&E publishing regions that fueled growth of S&E publications: the EU-15, Japan, and the East Asia-4. The volume of citations to U.S. literature, however, flattened in the late 1990s.

The increase in citation volume in most regions coincided with a growing share of citations to work done outside the author's country, reflecting the growing ease of access to worldwide scientific literature.

- Citations to literature produced outside the author's home country rose from 42% of all citations in 1992 to 48% in 2003.

The number of scientific articles cited by U.S. patents, an indicator of the linkage between science and technology, rose rapidly until the late 1990s.

- These increases were heavily centered in academic-authored articles in the fields of biomedical research and clinical medicine.

The growing closeness of basic science and practical applications is also evident in the rising number of U.S. patents issued to U.S. academic institutions.

- The number of U.S. academic patents quadrupled from approximately 800 in 1988 to more than 3,200 in 2003. The increase in patents was highly concentrated in life sciences applications.

Increases in licensing income and activity suggest growing efforts by universities to commercialize their products and technology.

- Income from licensing was more than $850 million in FY 2003, more than double the amount in FY 1997, and new licenses and options increased by more than 40% during this period.

Introduction

Chapter Overview

The academic sector continues to be a major contributor to the nation's scientific and technological progress, both through the generation of new knowledge and ideas and the education and training of scientists and engineers (see chapter 2). The nation's universities and colleges continue to perform more than half of the United States' basic research. The federal share of support for overall academic research and development, which had been declining for more than three decades, recently began increasing, and in 2003 the federal government provided more than 60% of the financial resources for academic R&D.

The allocation of the national academic R&D investment has been changing over time in several ways. More than half of all academic R&D funds now go to the life sciences. This share has grown over the past several decades, prompting discussion about the appropriate distribution of funds across disciplines. The number of academic institutions receiving federal support for R&D activities increased during the past three decades, expanding the base of the academic R&D enterprise beyond the traditional research institutions. Academic science and engineering infrastructure, both research equipment and research space, also grew over the past decade. However, the percentage of total annual R&D expenditures devoted to research equipment continued to decline.

Doctoral S&E faculty in universities and colleges play a critical role in ensuring an adequate, diverse, and well-trained supply of S&E personnel for all sectors of the economy. Demographic projections point to the potential for strong enrollment growth and the continuation of several trends—notably, more minority participation, more older students, and more nontraditional students. These changes are all likely to affect not only the composition but also the role of doctoral S&E faculty in the future. Recent hiring trends suggest movement away from the full-time faculty position as the academic norm. Academia may also be approaching a period of increasing retirements due to an aging labor force. Future trends for foreign graduate students and foreign-born faculty continue to be uncertain in the wake of the events of September 11, 2001, and the growing capacity in higher education in many countries.

The number of U.S. S&E articles published in the world's leading S&E journals has remained flat since the mid-1990s, whereas the number of articles published in the European Union (EU) and several East Asian countries has grown strongly. The number of influential articles from U.S. institutions, as measured by citation frequency, has likewise remained flat. As a result, the U.S. share of the world's influential articles has declined. Article output by the academic sector, which publishes most U.S. research articles, has mirrored the overall U.S. trend, even though research inputs (specifically, academic R&D expenditures and research personnel) have continued to increase. Academic scientists and engineers collaborate extensively with colleagues in other U.S. sectors, and international collaboration has increased significantly over the past two decades. The output of academic research has increasingly extended to patent protection of research results as the number of U.S. patents and other related activities has grown over the past two decades.

In this context, and driven by financial and other pressures, universities and colleges will continue to debate questions about their organization, focus, and mission. To help provide a context for such discussions, this chapter addresses key aspects of the academic R&D enterprise, including the role of the federal government and other funders in supporting academic research; the distribution of support across the nation's universities and colleges; the allocation of funding across S&E disciplines; research equipment and facilities at academic institutions; trends in the number and composition of the academic S&E doctoral labor force; and research outputs in the form of refereed journal articles and academic patents.

Chapter Organization

The first section of this chapter discusses trends in the financial resources provided for academic R&D, including providers of support and allocations across both academic institutions and S&E fields. Because the federal government has been the primary source of support for academic R&D for more than half a century, the importance of selected agencies to both overall support and support for individual fields is explored in some detail. This section also presents data on changes in the distribution of funds among academic institutions and on the number of academic institutions that receive federal R&D support. It concludes with an examination of the status of two key elements of university research activities: equipment and infrastructure.

The next section discusses trends in the employment of academic doctoral scientists and engineers and examines the positions they hold, their activities, and demographic characteristics. The discussion of employment trends focuses on full-time faculty, postdocs, graduate students, and other positions. Differences between the nation's leading research universities and other academic institutions are considered. The involvement of women and minorities is also examined, as are shifts in the faculty age structure. Attention is given to participation in research by academic doctoral scientists and engineers, the relative balance between teaching and research, and the provision of federal support for research. The section also reviews selected demographic characteristics of recent doctorate holders entering academic employment.

The chapter concludes with an analysis of trends in two types of research outputs: S&E articles, as measured by data from a set of journals covered by the *Science Citation Index (SCI)* and the *Social Sciences Citation Index (SSCI),* and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in this chapter and in chapter 2). This section looks specifically at the volume of research (article counts), collaboration in the conduct of research (joint authorship), use in subsequent scientific activity (citation patterns), and use beyond science (citations to the literature that are found in patent applications). It concludes with a discussion of academic patenting and some returns to academic institutions from their patents and licenses.

Financial Resources for Academic R&D

Academic R&D is a significant part of the national R&D enterprise.[1] To carry out world-class research and advance the scientific knowledge base, U.S. academic researchers require financial resources, stability of research support, and research facilities and instrumentation that facilitate high-quality work. Several funding indicators bear on the state of academic R&D, including:

- The level and stability of overall funding
- The sources of funding and changes in their relative shares
- The distribution of funding among the different R&D activities (basic research, applied research, and development)
- The distribution of funding among S&E broad and detailed fields
- The distribution of funding across institutions that perform academic R&D and the extent of their participation
- The role of the federal government as a supporter of academic R&D and the particular roles of the major federal agencies funding this sector
- The state of the physical infrastructure (research equipment and facilities)

Individually and in combination, these factors influence the evolution of the academic R&D enterprise and, therefore, are the focus of this section. The main findings are as follows:

- Continued growth in both federal and nonfederal funding of academic R&D
- A recent increase in the role of the federal government following a steady relative decline, and a corresponding relative decline in the roles of industry and state and local government
- A substantial increase in National Institutes of Health (NIH) funding relative to the other main federal funding agencies
- Continued but differential increases in funding for all fields, resulting in a relative shift in the distribution of funds, with increasing shares for the life sciences, engineering, and the computer sciences
- R&D activity occurring in a wider set of institutions, with the concentration of funds among the top research universities diminishing slightly
- The share of all annual R&D expenditures spent on research equipment reaching a historic low
- Continuous growth in academic S&E research space, particularly in the medical and biological sciences
- The increasingly important role of "cyberinfrastructure" in the conduct of S&E research.

For a discussion of the nature of the data used in this section, see sidebar, "Data Sources for Financial Resources for Academic R&D."

Academic R&D Within the National R&D Enterprise

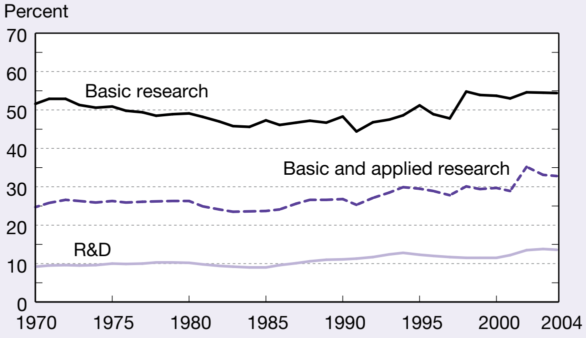
Academia is widely viewed as important to the nation's overall R&D effort, especially for its contribution to generating new knowledge through basic research. Since 1998, academia has accounted for more than half of the basic research performed in the United States.

In 2004, U.S. academic institutions spent an estimated \$42 billion, or \$39 billion in constant 2000 dollars, on R&D.[2] Academia's role as an R&D performer has increased during the past three decades, rising from about 10% of all R&D performed in the United States in the early 1970s to an estimated 14% in 2004 (figure 5-1). For a comparison with other countries, see chapter 4, "International R&D Comparisons."

Character of Work

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not include much development activity.[3] For the definitions used in National Science Foundation (NSF) surveys and a fuller discussion of these concepts, see chapter 4 sidebar, "Definitions of R&D." Recently, there has been some discussion

Figure 5-1
Academic R&D, basic and applied research, and basic research as proportion of U.S. totals: 1970–2004



NOTES: Data for 2003 and 2004 are preliminary. Because of changes in estimation procedures, character of work data before FY 1998 is not comparable with later years. Data based on annual reports by performers. For details on methodological issues of measurement, see National Science Foundation, Division of Science Resources Statistics (NSF/SRS), *National Patterns of Research and Development Resources: Methodology Report* (forthcoming).

SOURCE: NSF/SRS, *National Patterns of R&D Resources* (annual series). See appendix table 5-1. Also see appendix tables 4-3, 4-7, 4-11, and 4-15 for data underlying percentages.

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Data Sources for Financial Resources for Academic R&D

The data used to describe financial and infrastructure resources for academic R&D are derived from four National Science Foundation (NSF) surveys. These surveys use similar but not always identical definitions, and the nature of the respondents also differs across the surveys. The four main surveys are as follows:

- Survey of Federal Funds for Research and Development
- Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions
- Survey of Research and Development Expenditures at Universities and Colleges
- Survey of Science and Engineering Research Facilities

The first two surveys collect data from federal agencies, whereas the last two surveys collect data from universities and colleges. (For descriptions of the methodologies of the NSF surveys, see NSF 1995a and 1995b and the Division of Science Resources Statistics website, http://www.nsf.gov/statistics/.)

Data presented in the context section, "Academic R&D Within the National R&D Enterprise," are derived from special tabulations that aggregate NSF survey data on the various sectors of the U.S. economy so that the components of the overall R&D effort are placed in a national context. These data are reported on a calendar-year basis, and the data for 2003 and 2004 are preliminary. Since 1998, these data also attempt to eliminate double counting in the academic sector by subtracting current fund expenditures for separately budgeted science and engineering R&D that do not remain in the institution reporting them but are passed through via subcontracts and similar collaborative research arrangements to other institutions. Data in subsequent sections are reported on a fiscal-year basis and do not net out the funds passed through to other institutions, and therefore differ from those reported in this section. Data on major funding sources, funding by institution type, distribution of R&D funds across academic institutions, and expenditures by field and funding source are from the Survey of Research and Development Expenditures at Universities and Colleges. For various methodological reasons, parallel data by field from the NSF Survey of Federal Funds for Research and Development do not necessarily match these numbers.

The data in the "Federal Support of Academic R&D" section come primarily from NSF's Survey of Federal Funds for Research and Development. This survey collects data on R&D obligations from 30 federal agencies. Data for FY 2004 and 2005 are preliminary estimates. The amounts reported for FY 2004 and 2005 are based on administration budget proposals and do not necessarily represent actual appropriations. Data on federal obligations by S&E field are available only through FY 2003. They refer only to research (basic and applied) rather than to research plus development.

The data in the section "Spreading Institutional Base of Federally Funded Academic R&D" are drawn from NSF's Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions. This survey collects data on federal R&D obligations to individual U.S. universities and colleges from the approximately 18 federal agencies that account for virtually all such obligations. For various methodological reasons, data reported in this survey do not necessarily match those reported in the Survey of Research and Development Expenditures at Universities and Colleges.

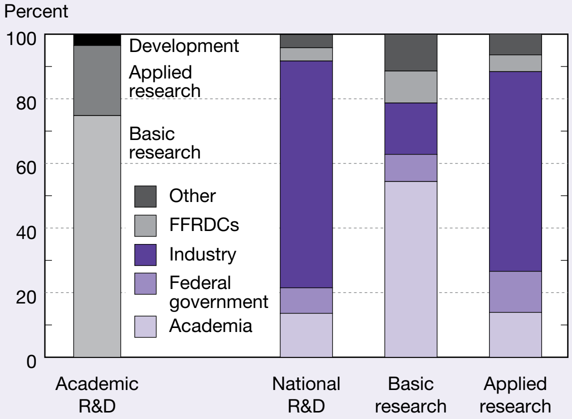
Data on research equipment are taken from the Survey of Research and Development Expenditures at Universities and Colleges. Data on research facilities and cyberinfrastructure are taken from the Survey of Science and Engineering Research Facilities. These two surveys do not cover the same populations. The minimum threshold for inclusion in the expenditures survey is $150,000 in expenditures, whereas the minimum threshold for inclusion in the facilities survey is $1 million. The facilities survey was redesigned for FY 2003 implementation and its topics broadened to include computing and networking capacity as well as research facilities. Data reported on various characteristics of research space are imputed for item nonresponse and weighted to national estimates for unit nonresponse. The data reported on networking and information technology planning are not imputed or weighted. Although terms are defined specifically in each survey, in general, *facilities expenditures* are classified as *capital* funds, are fixed items such as buildings, often cost millions of dollars, and are not included within R&D expenditures as reported here. *Research equipment and instruments* (the terms are used interchangeably) are generally movable, purchased with *current funds,* and included within R&D expenditures. Because the categories are not mutually exclusive, some large instrument systems could be classified as either facilities or equipment. Expenditures on research equipment are limited to current funds and do not include expenditures for instructional equipment. *Current funds,* as opposed to capital funds, are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

about whether a shift away from basic research and toward the pursuit of more utilitarian, problem-oriented questions is occurring in academia. (For a brief analysis of this issue, see sidebar "Has Academic R&D Shifted Toward More Applied Work?" later in this chapter.) For academic R&D expenditures in 2004, an estimated 97% went for research (75% for basic and 22% for applied) and 3% for development (figure 5-2). From the perspective of national research (basic and applied), as opposed to national R&D, academic institutions accounted for an estimated 33% of the U.S. total in 2004. In terms of basic research alone, the academic sector is the country's largest performer, currently accounting for an estimated 54% of the national total. Between the early 1970s and early 1980s, the academic sector's basic research share declined from slightly more to slightly less than one-half of the national total. In the early 1990s, its share of the national total began to increase once again.

Growth

Between 1970 and 2004, the average annual R&D growth rate (in constant 2000 dollars) of the academic sector (4.5%) was higher than that of any other R&D-performing sector except the nonprofit sector (4.7%). (See figure 5-3 and appendix table 4-4 for time-series data by R&D-performing sector.) As a proportion of gross domestic product (GDP), academic R&D rose from 0.24% to 0.37% during this period, a 50% increase. (See appendix table 4-1 for GDP time series.) Between 2000 and 2004, average annual R&D growth was higher in the academic sector (6.3%) than in any other sector except federally funded research and development centers (6.9%).

Figure 5-2
Academic R&D expenditures, by character of work, and national R&D expenditures, by performer and character of work: 2004



FFRDC = federally funded research and development center

NOTE: Data are preliminary.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources* (annual series). See appendix tables 4-3, 4-7, 4-11, and 5-1.

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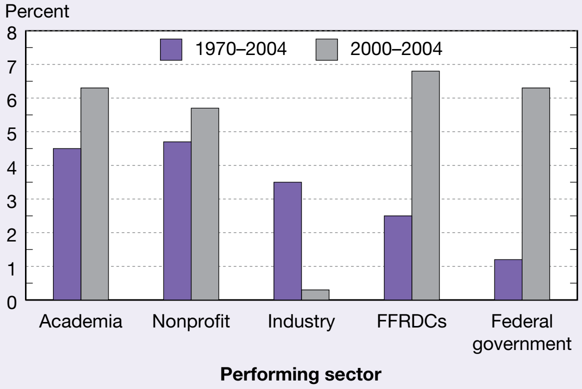
Figure 5-3
Average annual R&D growth, by performing sector: 1970–2004 and 2000–2004



FFRDC = federally funded research and development center

NOTES: R&D data are for calendar year. Data for 2003 and 2004 are estimated.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *National Patterns of R&D Resources,* special tabulations. See appendix table 4-4.

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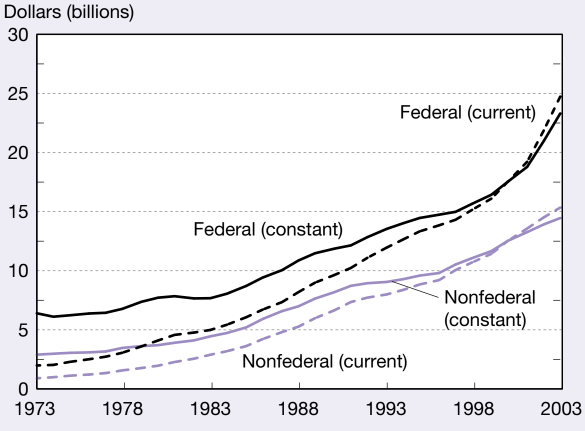
Major Funding Sources

The academic sector relies on a variety of funding sources for support of its R&D activities. The federal government continues to provide the majority of funds (figure 5-4). After declining for almost three decades, with most of the decline occurring during the 1980s, its share has recently begun to increase. In 2003, the federal government accounted for

Figure 5-4
Federal and nonfederal academic R&D expenditures: 1973–2003



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *Academic Research and Development Expenditures: Fiscal Year 2003* (forthcoming); and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-2.

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about 62% of the funding for R&D performed in academic institutions, compared with its peak of 69% in 1973 and 58% in 2000 (figure 5-5; appendix table 5-2).

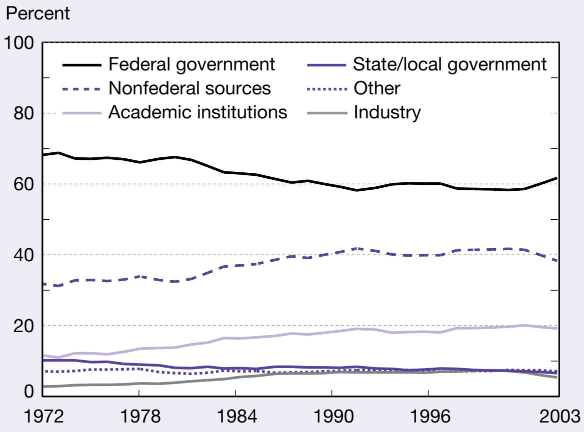
Federal support of academic R&D is discussed in detail later in this section. The following list summarizes the contributions of other sectors to academic R&D:[4]

- **Institutional funds.** In 2003, institutional funds from universities and colleges constituted the second largest source of funding for academic R&D, accounting for 19%, slightly below its peak of 20% in 2001 (appendix table 5-2). Institutional funds encompass two categories: (1) institutionally financed organized research expenditures and (2) unreimbursed indirect costs and related sponsored research. They do not include departmental research and thus exclude funds, notably for faculty salaries, in cases where research activities are not separately budgeted.

  The share of support represented by institutional funds had been increasing during the past three decades, except for a brief downturn in the early 1990s, but recently began to decline in 2001. Institutional R&D funds may be derived from (1) general-purpose state or local government appropriations (particularly for public institutions) or federal appropriations; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) unrestricted gifts. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues. (See "Patents Awarded to U.S. Universities" later in this chapter for a discussion of patent and licensing income.)

- **State and local government funds.** State and local governments provided 7% of academic R&D funding in 2003. Between 1980 and 2001, the state and local share of academic R&D funding fluctuated between 7% and 8%. However, the share has declined every year since 1996. This share, however, only reflects funds directly targeted to academic R&D activities by state and local governments. It does not include general-purpose state or local government appropriations that academic institutions designate and use to fund separately budgeted research or cover unreimbursed indirect costs.[5] Consequently, the actual contribution of state and local governments to academic R&D is not fully captured here, particularly for public institutions. (See chapter 8 for some indicators of academic R&D by state.)

Figure 5-5
Sources of academic R&D funding: 1972–2003



SOURCES: National Science Foundation, Division of Science Resources Statistics, *Academic Research and Development Expenditures: Fiscal Year 2003* (forthcoming); and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-2.

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- **Industry funds.** The funds provided for academic R&D by the industrial sector grew at a faster rate than funding from any other source during the 1973–2003 period. However, actual industry funding in inflation-adjusted dollars declined in both 2002 and 2003, the first time such a decline occurred in the past three decades. As a result, industry provided only 5% of academic R&D funding in 2003, a substantial decline from its peak of 7% in 1999. Industrial support accounts for the smallest share of academic R&D funding, and support of academia has never been a major component of industry-funded R&D. In 1994, industry's contribution to academic R&D represented 1.5% of its total support of R&D compared with 1.4% in 1990, 0.9% in 1980, and 0.7% in 1973. Between 1994 and 2004, this share declined from 1.5% to 1.1%. (See appendix table 4-4 for time-series data on industry-funded R&D.)

- **Other sources of funds.** In 2003, other sources of support accounted for 7% of academic R&D funding, a level that has stayed about the same since 1972. This category of funds includes grants for R&D from nonprofit organizations and voluntary health agencies and gifts from private individuals that are restricted by the donor to the conduct of research, as well as all other sources restricted to research purposes not included in the other categories.

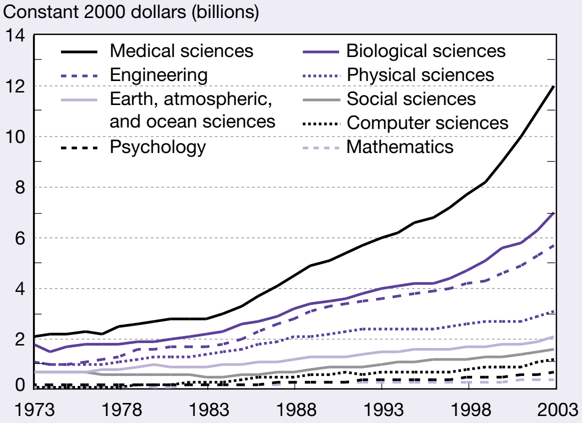
Expenditures by Field and Funding Source

The distribution of academic R&D funds across S&E disciplines often is the result of numerous, sometimes unrelated, funding decisions rather than an overarching plan. Examining and documenting academic R&D investment patterns across disciplines enables interested parties to assess the balance in the academic R&D portfolio. The majority of academic R&D expenditures in 2003 went to the life sciences, which accounted for 59% of total, federal, and nonfederal academic R&D expenditures (appendix table 5-3). Within the life sciences, the medical sciences accounted for 32% of total academic R&D expenditures and the biological sciences for 18%.[6] The next largest block of total academic R&D expenditures was for engineering: 15% in 2003.

The distribution of federal and nonfederal funding of academic R&D in 2003 varied by field (appendix table 5-4). For

Figure 5-6

Academic R&D expenditures, by field: 1973–2003



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *Academic Research and Development Expenditures: Fiscal Year 2003* (forthcoming); and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-5.

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example, the federal government funded about three-quarters of academic R&D expenditures in physics, the atmospheric sciences, and aeronautical/astronautical engineering but only about one-third in economics, political science, and the agricultural sciences.

The federally financed fraction of support for *each* of the broad S&E fields, except for computer sciences, was lower in 2003 than in 1980 (appendix table 5-4).[7] The most dramatic decline occurred in the social sciences, down from 54% in 1980 to 40% in 2003. The overall decline in federal share also holds for all the reported S&E subfields. However, most of the declines occurred in the 1980s, and many fields did not experience declining federal shares after that. In some fields, the federal share of support has increased since 1990.

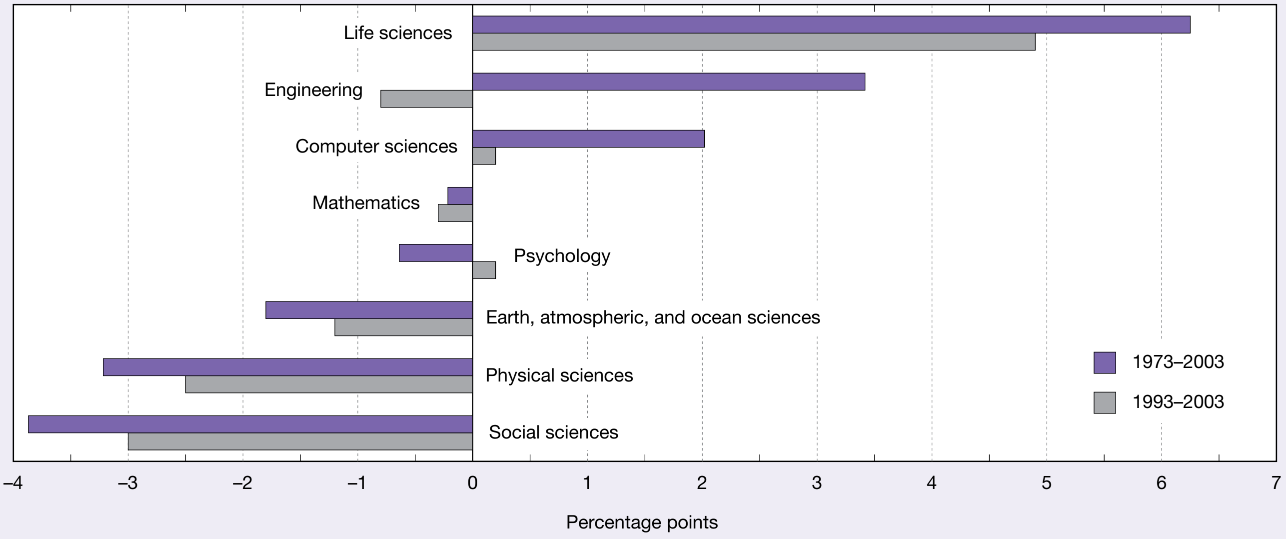
Although total expenditures for academic R&D in constant 2000 dollars increased in every field between 1973 and 2003 (figure 5-6; appendix table 5-5), the R&D emphasis of the academic sector, as measured by its S&E field shares, changed during this period (figure 5-7). Relative shares of academic R&D:

- Increased for the life sciences, engineering, and computer sciences
- Remained roughly constant for mathematics
- Declined for psychology; the earth, atmospheric, and ocean sciences; the physical sciences; and the social sciences

Although the proportion of the total academic R&D funds going to the life sciences increased by about 6 percentage points between 1973 and 2003, from 53% to 59% of academic R&D, the medical sciences' share increased by 10 percentage points during this period, from 22% to 32%, and the shares for the agricultural sciences and biological sciences both declined (appendix table 5-5). The largest declines in the proportion of total academic R&D funds were

Figure 5-7

Changes in share of academic R&D in selected S&E fields: 1973–2003 and 1993–2003



NOTE: Fields ranked by change in share during 1973–2003, in descending order.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *Academic Research and Development Expenditures: Fiscal Year 2003;* and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-5.

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in the social sciences and physical sciences, which declined by about 4 and 3 percentage points, respectively. When this analysis was limited to the period 1993–2003, similar trends in share changes were seen, with two exceptions: the engineering share declined by almost 1 percentage point, and the psychology share increased slightly.

Federal Support of Academic R&D

The federal government continues to provide the majority of the funding for academic R&D. Its overall contribution is the combined result of discrete funding decisions for several key R&D-supporting agencies with differing missions. Most of the funding provided by the federal government to academia reflects decisions arrived at through a competitive peer review process. Some of the funds are from long-established programs, such as those of the U.S. Department of Agriculture (USDA), that support academic research through formula funding rather than peer review, and other funds are the result of appropriations that Congress directs federal agencies to award to projects that involve specific institutions. These latter funds are known as *congressional earmarks.* (See sidebar, "A Brief Look at Congressional Earmarking.") Examining and documenting the funding patterns of the key funding agencies is key to understanding both their roles and that of the federal government overall.

Top Agency Supporters

Six agencies are responsible for most of the federal obligations for academic R&D, providing an estimated 96% of such obligations in FY 2005 (appendix table 5-6). NIH provided an estimated 66% of total federal financing of academic R&D in 2005. An additional 13% was provided by NSF; 7% by the Department of Defense (DOD); 5% by the National Aeronautics and Space Administration (NASA); 3% by the Department of Energy (DOE); and 2% by the USDA.[8] Federal obligations for academic research (i.e., without the development component) are concentrated similarly to those for R&D (appendix table 5-7). Some differences exist, however, because some agencies place greater emphasis on development (e.g., DOD), whereas others place greater emphasis on research (e.g., NIH).

Between 1990 and 2005, NIH's funding of academic R&D increased most rapidly, with an estimated average annual growth rate of 6.1% per year in constant 2000 dollars, increasing its share of federal funding from just above 50% to an estimated 66%. NSF and NASA experienced the next highest annual rates of growth: 3.9% and 3.6%, respectively.

Agency Support by Field

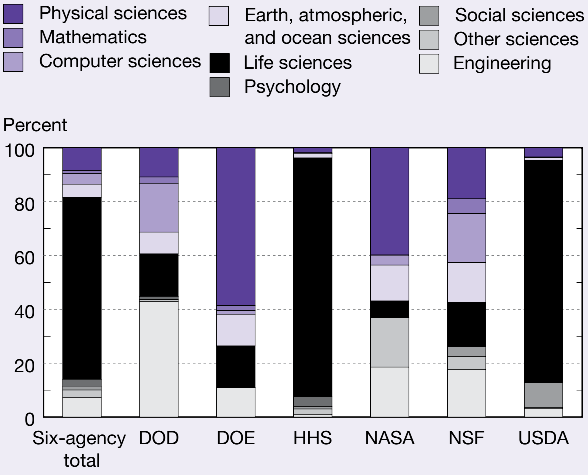
Federal agencies emphasize different S&E fields in their funding of academic research. Several agencies concentrate their funding in one field (e.g., the Department of Health and Human Services [HHS] and USDA in the life sciences and DOE in the physical sciences), whereas NSF, NASA, and DOD have more diversified funding patterns (figure 5-8; appendix table 5-8). Even though an agency may place a large share of its funds in one field, it may not be a leading contributor to that field, particularly if it does not spend much on academic research (figure 5-9).

In FY 2003, NSF was the lead federal funding agency for academic research in the physical sciences (31% of total funding); mathematics (69%); the computer sciences (66%); and the earth, atmospheric, and ocean sciences (43%) (appendix table 5-9). DOD and NSF were the lead funding agencies in engineering (37% and 35%, respectively). HHS was the lead funding agency in the life sciences (90%), psychology (96%), and the social sciences (46%). Within the S&E subfields, other agencies took the leading role: DOE in physics (46%), the USDA in the agricultural sciences (99%), and NASA in astronomy (78%) and astronautical engineering (73%). If the analysis is confined to basic academic research, which constituted 62% of federal obligations for academic research in 2003, the lead funding agencies by field differ slightly (table 5-1).

A Brief Look at Congressional Earmarking

Obtaining exact figures for either the amount of funds or the number of projects specifically earmarked for universities and colleges, either overall or for research, is often difficult because of the lack of an accepted definition of academic earmarking and because the funding legislation is often obscure in its description of the earmarked projects. However, a number of efforts have been undertaken to attempt to measure the extent of this activity. According to a recent analysis by the American Association for the Advancement of Science, R&D earmarks in the FY 2005 congressional appropriations bills were $2.1 billion, up 9% from FY 2004. These estimates include earmarks to all types of R&D performers. *The Chronicle of Higher Education* formerly estimated trends in academic earmarking through an annual survey of federal spending laws and the congressional reports that accompanied them. *The Chronicle's* latest analysis was for 2003, and its series shows steady increases in academic earmarks between 1996 and 2003, from $296 million to just over $2 billion. Not all of these funds, however, go to projects that involve research. Because the federal government provided about $23 billion for academic R&D expenditures in FY 2003, these estimates suggest less than 10% of federal academic R&D support is accounted for by earmarks. (For a more detailed historical discussion of earmarks, see sidebar "Congressional Earmarking to Universities and Colleges" in *Science and Engineering Indicators – 2004*.)

Figure 5-8
Federal agency academic research obligations, by field: FY 2003



DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture

NOTE: Agencies reported represent approximately 97% of federal academic research obligations.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming). See appendix table 5-8.

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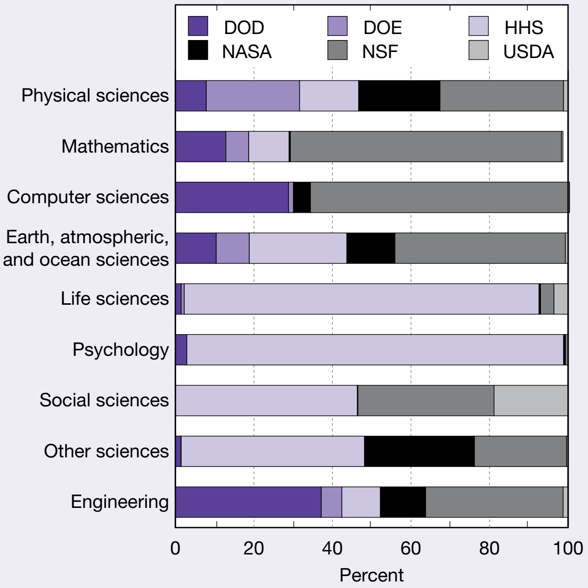
Figure 5-9
Major agency field shares of federal academic research obligations: FY 2003



DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture

NOTE: Agencies reported represent approximately 97% of federal academic research obligations.

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming). See appendix table 5-9.

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Table 5-1
Lead funding agency for academic basic research, by selected field: 2003

Field	Agency	Funded (%)
Physical sciences	NSF	40
Mathematics	NSF	76
Computer sciences	NSF	85
Earth, atmospheric, and ocean sciences	NSF	54
Life sciences	HHS	88
Psychology	HHS	95
Social sciences	NSF	52
Other sciences	NASA	35
Engineering	NSF	46

HHS = U.S. Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation

SOURCE: National Science Foundation, Division of Science Resources Statistics, *Federal Funds for Research and Development: Fiscal Years 2003, 2004, and 2005* (forthcoming).

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An Institutional Look at Academic R&D

The previous sections examined R&D for the entire academic sector. This section looks at some of the differences across institution types.

Funding for Public and Private Universities and Colleges

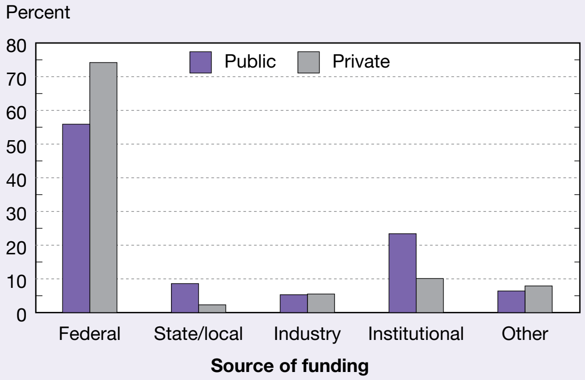
Although public and private universities rely on the same funding sources for their academic R&D, the relative importance of those sources differs substantially for these two types of institutions (figure 5-10; appendix table 5-10). For all *public* academic institutions combined, about 9% of R&D funding in 2003, the most recent year for which data are available, came from state and local funds; about 23% from institutional funds; and about 56% from the federal government. *Private* academic institutions received a much smaller portion of their funds from state and local governments (2%) and institutional sources (10%), and a much larger share from the federal government (74%). The difference in the role of institutional funds at public institutions may largely reflect the substantial amounts of general-purpose state and local government funds that public institutions receive and can decide to use for R&D (although data on such breakdowns are not collected).[9] (For a more detailed discussion of the composition of institutional funds for public and private academic institutions, see sidebar "The Composition of Institutional Academic R&D Funds.")

Both public and private institutions received approximately 5% of their R&D support from industry in 2003. The industry share of support for both public and private institutions decreased between 1993 and 2003, whereas both the federal and institutional shares of support increased.

Distribution of R&D Funds Across Academic Institutions

The distribution of R&D funds across academic institutions has been and continues to be a matter of interest both to those concerned with the academic R&D enterprise and those concerned with local and regional economic development. Most academic R&D is now, and has been historically, concentrated in relatively few of the 3,600 U.S. institutions of higher education.[10] If institutions are ranked by their 2003 R&D expenditures, the top 200 institutions account for about 95% of R&D expenditures that year. (See appendix table 5-11 for a more detailed breakdown of the distribution among the top 100 institutions.)

Figure 5-10
Sources of academic R&D funding for public and private institutions: 2003



SOURCES: National Science Foundation, Division of Science Resources Statistics, *Academic Research and Development Expenditures: Fiscal Year 2003* (forthcoming); and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-10.

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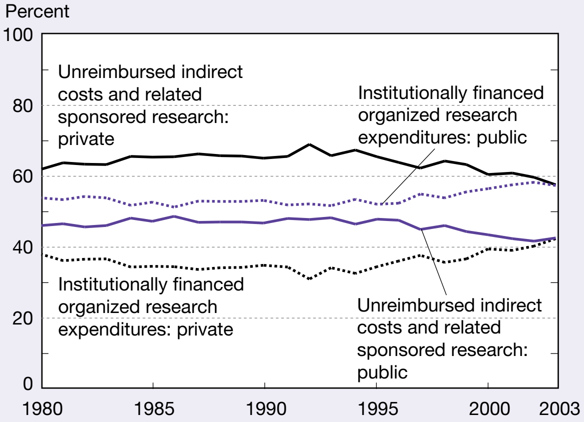
The historic concentration of academic R&D funds diminished slightly between the mid-1980s and mid-1990s but has remained relatively steady since then (figure 5-12). In 1983, the top 10 institutions received about 20% of the nation's total academic R&D expenditures, compared with 17% in 2003. There was almost no change in the shares of the group of institutions ranked 11–20 and 21–100 during this period. Consequently, the decline in the top 20 institutions' share was offset by an increase in the share of those institutions outside the top 100. This group's share increased from 17% to 20% of total academic R&D funds, signifying a broadening of the base of institutional performers.

It should be noted that the composition of the universities in any particular group is not necessarily the same over time, because mobility occurs within groups. For example, only 5 of the top 10 institutions in 1983 were still in the top 10 in 2003. The discussion later in this chapter

The Composition of Institutional Academic R&D Funds

During the past three decades, institutional funds for academic R&D grew faster than funds from any other sources except industry and faster than any other source in the past two decades (appendix table 5-2). In 2003, academic institutions committed a substantial amount of their own resources to R&D: roughly $7.7 billion, or 19% of total academic R&D. In 2003, the share of institutional support for academic R&D at public institutions (23%) was greater than that at private institutions (10%) (appendix table 5-10). One possible reason for this large difference in relative support is that public universities and colleges' own funds may include considerable state and local funds not specifically designated for R&D but used for that purpose by the institutions. Throughout the 1980s and most of the 1990s, institutional R&D funds were divided roughly equally between two components: (1) institutionally financed organized research expenditures and (2) unreimbursed indirect costs and related sponsored research. The balance shifted toward the former after 1998 as the latter share began to decline for both types of institutions. Institutional funds at public and private universities and colleges differ not only in their importance to the institution but also in their composition. Since 1980, from 58% to 69% of private institutions' own funds were designated for unreimbursed indirect costs plus cost sharing, compared with 42% to 49% of public institutions' own funds (figure 5-11).

Figure 5-11
Components of institutional R&D expenditures for public and private academic institutions: 1980–2003



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations.

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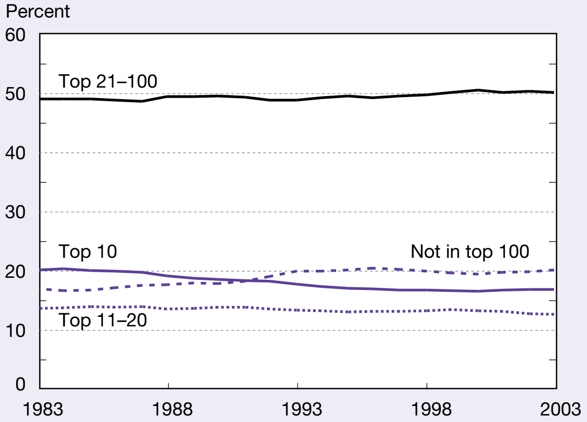
Figure 5-12

Share of academic R&D, by rank of university and college academic R&D expenditures: 1983–2003



SOURCES: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations; and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-11.

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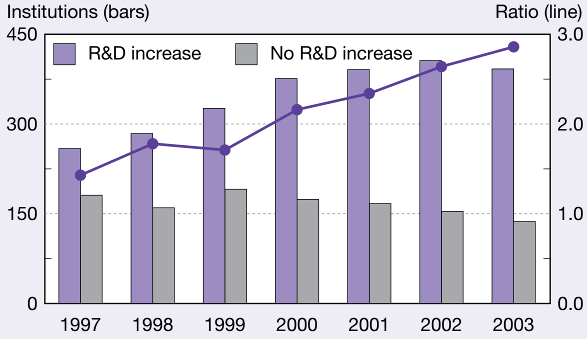
Figure 5-13

University and college R&D trends: 1997–2003



NOTE: Ratio is number of institutions reporting increased total R&D expenditures from prior year divided by number of institutions reporting either unchanged or decreased R&D expenditures from prior year.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, special tabulations; and *U.S. Academic R&D Continues to Grow as More Universities and Colleges Expand Their R&D Activities,* NSF 04-319 (2004).

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in “Spreading Institutional Base of Federally Funded Academic R&D” points to an increasing number of academic institutions receiving federal support for their R&D activities between 1972 and 2002. Many of the newer institutions receiving support are not the traditional Carnegie research and doctorate-granting institutions.

One program with the objective of improving the geographical distribution of federal academic R&D funds is the Experimental Program to Stimulate Competitive Research (EPSCoR). Several federal agencies have established EPSCoR or EPSCoR-like programs. EPSCoR attempts to increase the R&D competitiveness of eligible states through developing and using the science and technology resources resident in a state’s major research universities. Eligibility for EPSCoR participation is limited to jurisdictions that have historically received lesser amounts of federal R&D funding and have demonstrated a commitment to develop their research bases and improve the quality of the S&E research conducted at their universities and colleges.

Changes in R&D Expenditures Across Academic Institutions

As academic R&D expenditures grew between 1997 and 2003, more institutions expanded their R&D activities. In FY 2003, as in the 6 preceding years, a greater number of institutions reported increased R&D expenditures than reported decreased R&D expenditures (figure 5-13). In fact, an examination of the ratio of the number of institutions increasing their expenditures from one year to the next to the number that did not increase their expenditures shows a fairly steady rise in this ratio during this period (figure 5-13). In FY 1997, approximately 1.4 institutions reported increased expenditures over FY 1996 for each institution that reported either unchanged or decreased R&D expenditures. In FY 2003, 2.9 institutions, more than twice as many as in 1997, increased their R&D expenditures for each institution that did not.[11]

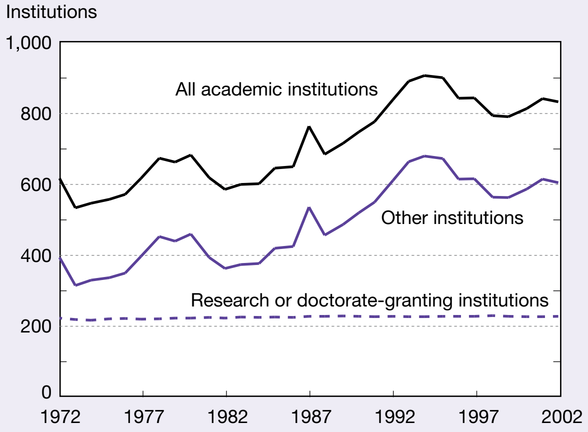
Spreading Institutional Base of Federally Funded Academic R&D

The number of academic institutions receiving federal support for their R&D activities increased fairly steadily between 1972 and 1994, when it reached a peak of 907 institutions. Between 1995 and 2002, the number of institutions receiving federal support fluctuated between 791 and 901 (figure 5-14).[12] These fluctuations almost exclusively affected institutions of higher education with Carnegie classifications of comprehensive; liberal arts; 2-year community, junior, and technical; and professional and other specialized schools. The number of such institutions receiving federal support more than doubled between 1973 and 1994, rising from 315 to 680. It then dropped to 563 by 1999 before beginning to rise again in the past several years (appendix table 5-12). These institutions’ share of federal support also increased between 1972 and 2002, from 9% to just above 14%. The number of Carnegie research and doctorate-granting institutions receiving federal support remained relatively constant during this period.

Academic R&D Equipment

Research equipment is an integral component of the academic R&D enterprise. This section examines expenditures on research equipment, the federal role in funding these expenditures, and the relation of equipment expenditures to overall R&D expenditures.

Figure 5-14
Academic institutions receiving federal R&D support, by selected Carnegie classification: 1972–2002



NOTES: Other institutions include all institutions except Carnegie research and doctorate-granting institutions. Institutions designated by 1994 Carnegie classification code. For information on these institutional categories, see chapter 2 sidebar, "Carnegie Classification of Academic Institutions."

SOURCES: National Science Foundation, Division of Science Resources Statistics, *Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions: FY 2002,* NSF 05-309 (2005); and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-12.

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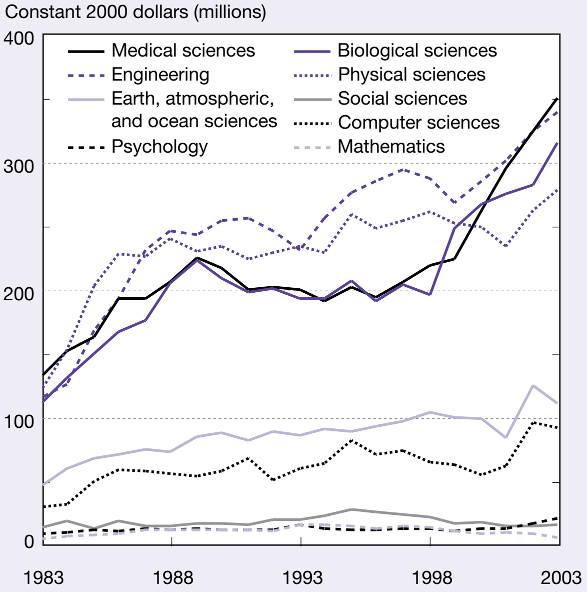
Figure 5-15
Current fund expenditures for research equipment at academic institutions, by field: 1983–2003



NOTE: See appendix table 4-1 for gross domestic product implicit price deflators used to convert current dollars to constant 2000 dollars.

SOURCES: National Science Foundation, Division of Science Resources Statistics, *Academic Research and Development Expenditures: Fiscal Year 2003* (forthcoming); and WebCASPAR database, http://webcaspar.nsf.gov. See appendix table 5-13.

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Expenditures

In 2003, about $1.8 billion in current funds was spent for academic research equipment. About 81% of these expenditures were concentrated in three fields: the life sciences (45%), engineering (20%), and the physical sciences (16%) (figure 5-15; appendix table 5-13).

Current fund expenditures for academic research equipment grew at an average annual rate of 4.6% (in constant 2000 dollars) between 1983 and 2003. However, recent annual growth (since 2000) was almost 6%, compared with less than 1% during the 1990s. The growth patterns in S&E fields varied during this period. For example, equipment expenditures for engineering (5.5%) and the biological sciences (5.2%) grew more rapidly during the 1983–2003 period than did those for the social sciences (0.7%) and agricultural sciences (0.5%).

Federal Funding

Federal funds for research equipment are generally received either as part of research grants or as separate equipment grants, depending on the funding policies of the particular federal agencies involved. The importance of federal funding for research equipment varies by field. In 2003, the social sciences received about 45% of their research equipment funds from the federal government; in contrast, federal support accounted for more than 70% of equipment funding in the physical sciences, mathematics, the computer sciences, psychology, and the earth, atmospheric, and ocean sciences (appendix table 5-14). The share of research equipment expenditures funded by the federal government declined from 62% to 55% between 1983 and 2001, but thereafter rose to 63% in 2003. This overall pattern masks different trends in individual S&E fields.

R&D Equipment Intensity

R&D equipment intensity is the percentage of total annual R&D expenditures from current funds devoted to research equipment. This proportion has been declining fairly steadily since reaching its peak in 1986 (7%). By 2003, it had declined to 5% (appendix table 5-15). R&D equipment intensity varies across S&E fields, tending to be higher in the physical sciences (about 9% in 2003) and lower in the social sciences (1%) and psychology (3%).

Several years ago, Congress requested that an NSF National Survey of Academic Research Instrumentation, last conducted in 1994, be reinstated to determine the extent to which a lack of equipment and instrumentation prevents the academic research community from undertaking cutting-edge, world-class science. NSF is investigating the feasibility of obtaining such information.

Academic R&D Infrastructure

The physical infrastructure of academic institutions is critical to supporting R&D activities. Traditional indicators of the status of the research infrastructure are the amount of research space currently available and the amount of investment in future facilities. Furthermore, the quality of research space is a key factor in the types of research that can be undertaken.

In addition to the traditional "bricks and mortar" research infrastructure, "cyberinfrastructure" is playing an increasingly important role in the conduct of S&E research. Technological advances are significantly changing S&E research methods. In some cases, advanced technology is already changing the role of traditional bricks and mortar facilities. According to the NSF Advisory Panel on Cyberinfrastructure, these advances are not simply changing the conduct of science but are revolutionizing it (NSF 2003). The panel defined *cyberinfrastructure* as the "infrastructure based upon distributed computer, information and communication technology" (NSF 2003, p 1.2). The report discusses the current and potential future importance of cyberinfrastructure, stating that "digital computation, data, information and networks are now being used to replace and extend traditional efforts in science and engineering research" (NSF 2003, p 1.1).

At this time, how the relationship between cyberinfrastructure and traditional bricks and mortar infrastructure will play out is unknown. Access to high-quality research facilities may become available to researchers located at institutions where traditional research space has not been available. Some institutions now indicate they need less physical space as they begin to conduct research not in their own laboratories or research facilities but through networking and/or high-performance computing, communicating with research facilities thousands of miles away or accessing very large databases generated by advanced data collection technologies.

Bricks and Mortar

Research Space. Research-performing colleges and universities[13] continued to expand their stock of research space in FY 2003 with the largest increase in total research space since 1988. By the end of FY 2003, total research space increased 11% from FY 2001 to approximately 173 million net assignable square feet (NASF)[14] (table 5-2). This increase was substantially greater than any previous 2-year increase since FY 1988 and continued a trend of increases in the amount of academic research space. During this 15-year period, the amount of research space increased biennially at a rate of at least 4%.

Except for the agricultural sciences, all S&E fields experienced increases in research space between FY 2001 and FY 2003. Two fields, the computer sciences and mathematics, experienced the largest increases (but their total space was the smallest among all S&E fields). Social science space increased by 27%. Growth in medical sciences research space, 26%, was the fourth highest, reaching 35 million NASF. Only the biological sciences had more research space (36 million NASF). These two fields, combined with engineering, accounted for 57% of all research space at the end of FY 2003.

Little change occurred in the distribution of research space across S&E fields during this 15-year period. The largest increase in the share of total research space occurred in the medical sciences. However, this share only changed 3 percentage points between 1988 and 2003. The engineering

Table 5-2
S&E research space in academic institutions, by field: FY 1988–2003
(Millions of net assignable square feet)

Field	1988	1990	1992	1994	1996	1998	1999	2001	2003
All fields	112	116	121	127	136	143	148	155.1	172.6
Physical sciences	16	16	17	17	18	18	19	19.2	20.4
Mathematics	1	1	1	1	1	1	1	1.0	1.5
Computer sciences	1	1	2	2	2	2	2	2.4	3.1
Earth, atmospheric, and ocean sciences	6	6	7	7	7	8	8	8.1	8.9
Agricultural sciences	18	21	20	20	22	25	24	27.8	26.4
Biological sciences	24	27	28	28	30	31	31	33.4	36.0
Medical sciences	19	20	23	23	25	25	26	27.8	34.9
Psychology	3	3	NA	3	3	3	4	4.5	4.4
Social sciences	3	3	NA	3	4	5	3	4.5	5.7
Other sciences	4	2	2.0	2	2	3	3	3.0	3.8
Engineering	16	17	21	21	22	23	24	25.5	27.4
Animal research space	NA	NA	NA	11	12	12	13	NA	16.7

NA = not available

NOTES: Animal research space listed separately and also included in individual field totals. Detail may not add to total because of rounding.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 1988–2003.

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share of total research space increased 2 percentage points. The largest decrease, only 2 percentage points, occurred in the physical sciences.

Construction of Research Space. Universities invested $7.6 billion in FY 2002–03 in the construction of 16 million NASF of research space (appendix tables 5-16 and 5-17).[15] Almost half of all universities began construction projects (NSF/SRS forthcoming).

Although universities began construction of research space in all S&E fields in FY 2002–03, the largest share of space under construction (56%) was for research in the medical sciences and biological sciences (appendix table 5-17). Fifty-six percent of research space construction started in FY 2002 or FY 2003 is to be used for research in these two fields. If engineering research space is included, these three fields account for about 70% of the new construction started. Even if some newly constructed space replaces existing space, the share of newly constructed space in the medical sciences (31%) was substantially greater than that of any other field, and therefore would not likely change the overall field distribution. The biological sciences, which had the second largest share, accounted for 25% of newly constructed research space.

If the universities were able to follow through on planned construction for FY 2004 and FY 2005, the medical sciences and biological sciences will likely continue to dominate the share of total research space (appendix table 5-17). Universities plan to construct 19 million NASF of research space during this period at an estimated cost of $9.1 billion. The biological sciences and medical sciences will account for 53% of the planned space and 61% of estimated construction costs (appendix tables 5-16 and 5-17).

Funds for Construction. Institutions use one or more sources to fund their capital projects, including the federal government, state or local governments, and the institutions' own funds.[16] The federal government's share of total construction funding has been declining and reached its smallest proportion (5%) since 1986–87 in FY 2002–03 (figure 5-16; appendix table 5-18). During the same period, the institutional share of construction funds increased overall and reached its highest share, 63%, in FY 2002–03.

Over time, the share of institutional funds universities and colleges have allocated for repair/renovation of research space has been consistently greater than the share they have allocated for construction. However, even for repair/renovation, the institutional share of total funds reached its highest level since 1988, 71%, in FY 2002–03 (NSF/SRS forthcoming).

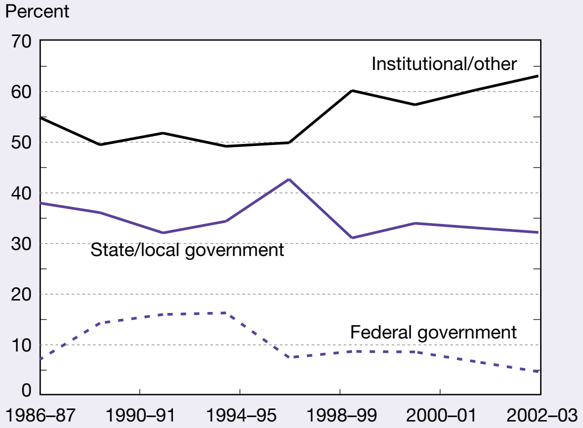
Unmet Needs. Determining the capital infrastructure needs of universities has at least several dimensions. Two indicators of need are the dollar value of deferred projects and the quality of existing space.

Deferred projects are projects in a university's institutional plans that are needed for current program commitments but that have not yet been funded and therefore are not scheduled to begin. Institutions reported approximately $8.4 billion in deferred construction projects in FY 2003 (appendix table 5-16). More than half of this deferred construction was in the biological sciences and medical sciences.

There are no objective criteria to determine how much of a field's research actually requires state-of-the-art space. However, space rated as needing replacement *can* be seen as an indicator of need. In FY 2003, institutions rated 30% of their existing space as state of the art and 79% as either state of the art or suitable for most levels of research and reported that 5% should be discontinued as research space within the next 2 years (appendix table 5-19).[17] The amount of space needing replacement varied little by field, ranging from 7% in the social sciences and earth, atmospheric, and ocean sciences to 2% in mathematics.

Perhaps not surprisingly, the computer sciences, the field that had the greatest amount of relative growth in research space between FY 2001 and FY 2003, rated the largest percentage of its space as state of the art. The medical sciences, another field that experienced a large increase in the amount of new space during this period, had the second highest amount of space rated as state of the art.

Figure 5-16
Source of funds for construction: 1986–87 to 2002–03



NOTE: Data extrapolated for 2000–01 period because data not collected.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Years 1986–2003. See appendix table 5-18.

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Cyberinfrastructure: Networking

Networking resources are a key component of cyberinfrastructure. Networks allow users and researchers to communicate and transfer data both within a specific institution's boundaries and with others around the world. At many institutions, the same networks are used for multiple academic functions such as instruction, research, and administration.[18]

All academic institutions today have network connections to the *commodity Internet,* or *Internet1,* the network commonly known as the Internet. Although Internet connections are used for many purposes (e.g., e-mail, buying books from the campus bookstore), conducting research can require higher capabilities of network connections than other activities.

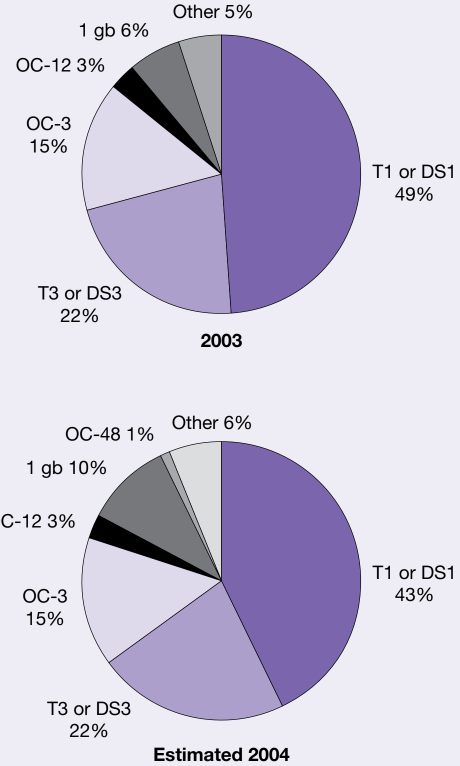
There are numerous indicators of network capability. One common indicator is bandwidth, or speed. A network's bandwidth can affect the amount and type of research activity accomplished through the network. The faster the network speed, the more capable the network is in handling both large amounts of data and communication traffic and more demanding or sophisticated communications. Whereas a slow network connection might well be able to transmit scientific articles, transmitting scientific instruments located thousands of miles away or accessing large databases demands (among other requirements) high bandwidth or fast speed.

Desktop Connection Speed. The speed of the desktop computer's connection to the campus network will likely differ from that of the campus network's connection to the Internet. Generally, researchers access the Internet from their desktop computers. Therefore, the speed of the desktop connection to the institution's campus network is one useful indicator of an institution's network capability. Desktop connection speeds will vary across an institution. Almost 75% of academic institutions reported the highest operating speed of the majority of their desktop connections (ports) as 100 megabits/second in FY 2003, and 1% reported it as 1 gigabit/second (NSF/SRS forthcoming).

In FY 2003, 76% of non-doctorate-granting institutions had the majority of their desktop connections at 100 megabits/second or faster, compared with 71% of doctorate-granting institutions (appendix table 5-20). However, only 19% of non-doctorate-granting institutions estimated their *highest* speed as 1 gigabit/second, compared with 46% of doctorate-granting institutions. Most institutions planned to obtain faster connection speeds in FY 2004, and 52% of all institutions estimated that their highest connection speed would be 1 gigabit/second at the end of FY 2004.

Internet Connection Speed. Another critical point is the connection between the institution's campus network and the Internet. At the end of FY 2003, most universities had multiple connections to the Internet at a variety of speeds. The majority (49%) were at the lowest speed, 1.5 megabits/second (i.e., T1 or DS1 lines). The second largest share of connections (22%) was at the next lowest speed, 45 megabits/second (i.e., T3 or DS3 lines). Together, these two speeds accounted for 71% of connections (figure 5-17; appendix table 5-21). However, at least 6% of connections were at 1 gigabit/second or faster. Doctorate-granting institutions had the largest number of high-speed connections. Although the greatest *number* of connections was at 1.5 or 45 megabits/second, the *highest connection speed* was 155 megabits/second or faster at 45% of all institutions and 1 gigabit/second or faster at 12% (table 5-3).

Figure 5-17
Internet connection speed: 2003 and 2004



gb = gigabits/second

NOTE: 2004 data estimated.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Year 2003. See appendix table 5-21.

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Overall, institutions did not anticipate a large increase in the total number of Internet connections between FY 2003 and FY 2004. However, institutional plans overall called for fewer connections at slower speeds and a larger number at faster speeds, estimating a 4% increase in the number of connections at speeds of 1 gigabit or higher by the end of FY 2004. Both doctorate-granting and non-doctorate-granting institutions anticipated increases in connection speeds. In fact, non-doctorate-granting institutions estimated fewer total connections overall but more at higher speeds. Furthermore, both doctorate- and non-doctorate-granting institutions expected to increase the speed of their highest speed connections by the end of FY 2004.

Wireless and High-Performance Network Connections. In addition to their hardwire network connections, many universities have wireless Internet connections as well as connections to advanced or high-performance networks. High-performance networks are not only faster than the Internet but also have other characteristics important to conducting research. At the end of FY 2003, 65% of academic institutions had connections to Abilene (often called *Internet2*) (NSF/SRS

Table 5-3
Highest institutional connection speed to commodity Internet (Internet1), by type of institution: FY 2003 and 2004
(Percent distribution)

Type of institution	Number of connections	T1/DS1 (1.5 mb)	T3/DS3 (45 mb)	OC-3 (155 mb)	OC-12 (622 mb)	1 gb	OC-48 (2.4 gb)	Other
FY 2003								
All academic	424	9	36	29	4	11	1	10
Doctorate granting	301	6	29	32	6	14	1	12
Nondoctorate granting	123	15	54	20	2	2	1	7
FY 2004 (estimated)								
All academic	420	5	33	26	6	16	1	13
Doctorate granting	299	5	25	28	7	20	1	14
Nondoctorate granting	121	7	51	22	3	7	1	9

mb = megabits/second; gb = gigabits/second

NOTES: Some institutions reported connection speeds in category “other.” Detail may not add to total because of rounding or absence of commodity Internet (Internet1) connection.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Science and Engineering Research Facilities, Fiscal Year 2003.

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forthcoming), a high-performance network dedicated to research led by a consortium of universities, governments, and private industry. A substantially larger proportion (79%) of doctorate-granting institutions had Abilene connections as compared with non-doctorate-granting institutions (28%).

Although wireless networking is used less frequently for research, universities are moving toward greater institutional coverage by wireless networking. At the end of FY 2003, 67% of institutions had 20% or less of their building areas covered by wireless network connections (NSF/SRS forthcoming). However, less than 30% estimated that their coverage would be 20% or less by the end of FY 2004.

Doctoral Scientists and Engineers in Academia

The pursuit of new knowledge, the training of the people in whom that knowledge is embodied, and its use in generating innovation make academia a national resource whose vitality rests in the scientists and engineers who study and work there. Especially important are those with doctorates who do the research, teach and train the students, and stimulate or help to produce innovation.[19]

Employment and research activity at the leading research-performing universities in the United States merit special attention.[20] These institutions have a disproportionate influence on the nation’s academic science, engineering, and R&D enterprise. Although they enroll only 22% of full-time undergraduates and award 32% of all bachelor’s degrees, they award 39% of bachelor’s degrees in S&E fields. Of U.S. S&E doctorate holders with a U.S. baccalaureate degree, research universities are the source of 55% of all of them and the source of more than 60% of those who are employed in academia and report R&D as their primary work activity. Moreover, these institutions conduct more than 80% of academic R&D (as measured by expenditures) and produce the bulk of both academic articles and patents. (See “Outputs of S&E Research: Articles and Patents” later in this chapter.)

Growth in academic employment over the past half century reflected both the need for teachers, driven by increasing enrollments, and an expanding research function, largely supported by federal funds. Trends in indicators related to research funding are presented earlier in this chapter. This section presents indicators about academic personnel. Unless otherwise indicated, the discussion is limited to those who received their S&E doctorate at a U.S. institution. Because of the complex interrelationship between academic teaching and research, much of the discussion deals with the overall academic employment of S&E doctorate holders, specifically, the relative balance between faculty and nonfaculty positions, demographic composition, faculty age structure, hiring of new doctorate holders, trends in work activities, and trends in federal support. The section also examines the academic research workforce: its definition and size; its deployment across institutions, positions, and fields; and the extent to which it is receiving federal support. Finally, a previously mentioned sidebar, “Has Academic R&D Shifted Toward More Applied Work?,” briefly discusses whether a shift away from basic research toward more applied R&D activities has been occurring.

The main findings are a relative shift in the employment of S&E doctorate holders away from the academic sector toward other sectors; a slower increase in full-time faculty positions than in postdoc and other full- and part-time positions; a relative shift in hiring away from white males toward women and minorities; an increasing proportion of foreign-born faculty and postdocs; an aging academic doctoral labor force; a decline in the share of academic researchers who report receiving federal support; and growth of an academic researcher pool outside the regular faculty ranks.

Trends in Academic Employment of Doctoral Scientists and Engineers

Academic employment of S&E doctorate holders reached a record high of 258,300 in 2003.[21] However, long-term growth in the number of these positions between 1973 and 2003 was slower than in either business or government. Growth in the academic sector was also much slower between 1983 and 2003 than it was between 1973 and 1983 (table 5-4). As a result, the share of all S&E doctorate holders employed in academia dropped from about 55% to 45% during the 1973–2003 period (table 5-5). Beginning in the 1990s, the share of those with recently awarded degrees (that is, a degree awarded within 3 years of the survey year) employed in academia was generally substantially higher than the overall academic employment share for S&E doctorate holders, possibly reflecting the relatively large number of young doctorate holders in postdoc positions. In 2003, more than half of recent doctorate holders were employed in academia.

Academic Hiring

Employment growth over the past decade was much slower at the research universities than at other academic institutions. Appendix table 5-22 breaks down academic employment by type of institution. From 1993 to 2003, doctoral S&E employment at research universities grew by 1.2% annually, whereas employment at other institutions increased by 2.6% annually. During the same period, employment increased slightly less rapidly at public universities and colleges than at their private counterparts (1.2% versus 1.4% a year) and employment at both public and private research universities grew much more slowly than overall employment (figure 5-18; table 5-4; appendix table 5-23).

All Academic S&E Doctoral Employment

Trends in academic employment of S&E doctorate holders suggest continual movement away from the full-time faculty position as the academic norm. Overall academic employment of S&E doctorate holders grew from 118,000 in 1973 to 258,300 in 2003 (appendix table 5-24). However, during this period, full-time faculty positions increased more slowly than postdoc and other full- and part-time positions. This trend accelerated between 1993 and 2003, with the full-time faculty growth rate at less than two-thirds the overall growth rate (table 5-6).

Figure 5-19 shows the resulting distribution of academic employment of S&E doctorate holders. The overall faculty share was 75% of all academic employment in 2003, down from 87% in the early 1970s. The share of full-time senior faculty fell from just over 60% of total employment in 1993 to less than 55% in 2003. The share of junior faculty fluctuated between 18% and 21% between 1983 and 2003. These employment trends, particularly during the 1993–2003 period, occurred as real spending for academic R&D rose by two-thirds, retirement of faculty who were hired during the 1960s increased, academic hiring of young doctorate holders showed a modest rebound, and universities displayed greater

Table 5-4
Average annual growth rate for employment of S&E doctorate holders in U.S. economy: 1973–2003
(Percent)

Sector	1973–2003	1973–83	1983–93	1993–2003
All sectors	3.3	5.4	2.5	2.0
Academia	2.6	4.1	2.0	1.9
Research universities	2.2	3.2	2.3	1.2
Other	3.2	5.0	1.6	2.6
Business	4.9	7.9	4.1	2.7
Government	3.7	5.5	2.5	3.1
Other	1.4	5.3	0.5	–1.6

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Table 5-5
S&E doctorate holders employed in academia, by years since doctorate: Selected years, 1973–2003
(Percent)

Years since doctorate	1973	1983	1993	2003
Employed doctorate holders	54.8	48.4	45.9	45.5
≤3	55.2	48.0	50.5	53.5
4–7	55.8	44.9	47.0	46.2
>7	54.2	49.4	45.0	44.2

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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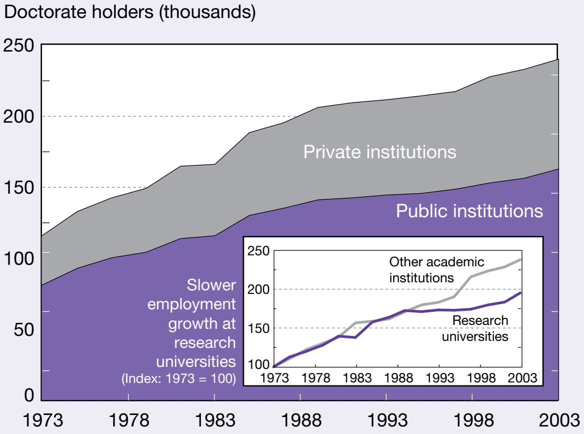
Figure 5-18
S&E doctorate holders employed in public and private universities and colleges: 1973–2003



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-23.

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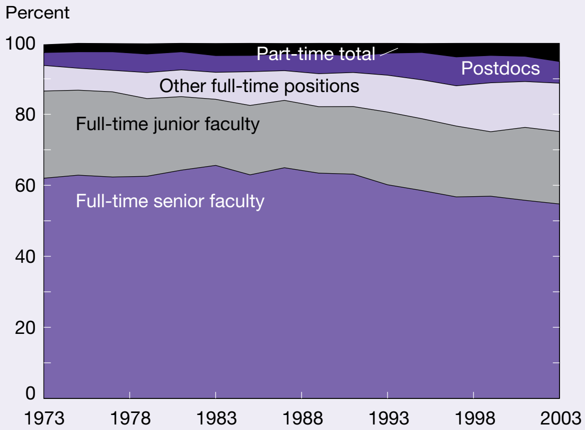
Figure 5-19
S&E doctorate holders, by type of academic appointment: 1973–2003



NOTES: Junior faculty includes assistant professors and instructors. Senior faculty includes full and associate professors. Other full-time positions include nonfaculty positions such as research associates, adjunct appointments, lecturers, and administrative positions.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-23.

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interest in the practical application of academic research results (discussed later in this chapter).[22]

Nonfaculty ranks, that is, full- and part-time adjunct faculty, lecturers, research and teaching associates, administrators, and postdocs, increased from 41,400 in 1993 to 64,200 in 2003. This 55% increase stood in sharp contrast to the 13% rise in the number of full-time faculty. Both the full-time nonfaculty and part-time components grew rapidly between 1993 and 2003. Postdocs rose more slowly during this period and, in fact, actually declined after 1997 after quite substantial growth up to that year.[23] Part-time employees accounted for only a small share (between 2% and 4%) of all academic S&E doctoral employment throughout most of the period before rising to just above 5% in 2003 (appendix table 5-24).

Recent S&E Doctorate Holders

The trends discussed above reflect the entire academic workforce of S&E doctorate holders. Another picture of current trends can be found by looking at the academic employment patterns of those with recently awarded S&E doctorates (degrees earned at U.S. universities within 3 years of the survey year).

Table 5-6
Average annual growth rate for S&E doctorate holders, by academic position: 1973–2003
(Percent)

Academic position	1973–2003	1973–83	1983–93	1993–2003
All positions	2.6	4.1	2.0	1.9
Full-time faculty	2.1	3.7	1.5	1.2
Professors	2.4	5.1	1.4	0.9
Associate professors	1.8	3.8	0.6	1.1
Junior faculty	2.0	1.1	2.9	1.9
Full-time nonfaculty	5.3	5.9	5.2	4.7
Postdocs	4.5	7.2	4.8	1.7
Part-time positions	5.2	7.4	–0.2	8.4

NOTES: Junior faculty includes assistant professors or instructors. Nonfaculty includes positions such as research associates, adjunct appointments, lecturers, and administrative positions.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-23.

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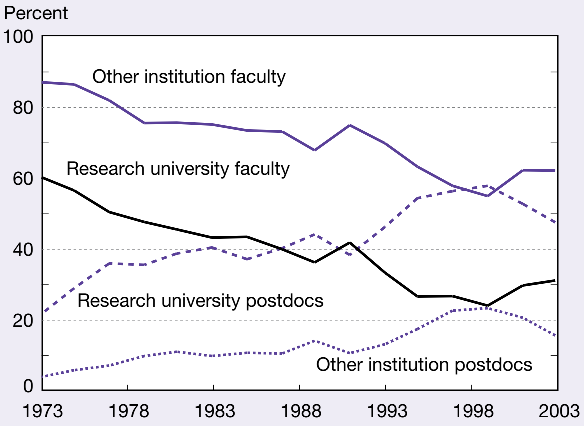
Recent S&E doctorate holders who entered academic employment at research universities were more likely to be in postdoc than in faculty positions (figure 5-20; appendix table 5-25). Between 1973 and 2003, the share of recent doctorate holders hired into full-time faculty positions fell by more than 40%, from 74% to 44%. The decline in such employment at research universities was slightly steeper, from 60% to 31%. Conversely, the overall share of recent S&E doctorate holders who reported being in postdoc positions rose from 13% to 34% (from 22% to 48% at research universities). However, after increasing throughout the 1990s, the share of recent S&E doctorate holders in postdoc positions reached its peak level in 1999, after which it declined overall and at research universities.

Young Doctorate Holders With a Track Record

For those employed in academia 4–7 years after earning their doctorates, the picture looks quite similar: about 65% had faculty rank in 2003, compared with about 89% in 1973. Before increasing slightly between 2001 and 2003, the trend had been continuing downward since 1991. A little more than half of these doctorate holders were in tenure-track positions in 2003, with about 13% already tenured. The shares of both those in tenure-track positions and those with tenure declined between 1991 and 2001 and increased in 2003. Whether or not the 2003 figures mark the beginning of a trend remains to be seen (figure 5-21). Trends at research universities were similar. However, at the research universities, the share of those in faculty, tenured, or tenure-track positions was much smaller than at other academic institutions (appendix table 5-25).

Figure 5-20
S&E doctorate holders with recent degrees employed at research universities and other academic institutions, by type of position: 1973–2003



NOTES: Recent doctorate holders earned degrees within 3 years of survey. Faculty employed full time as full, associate, and assistant professors and instructors. Not all positions are shown.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-25.

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Shift in Employment

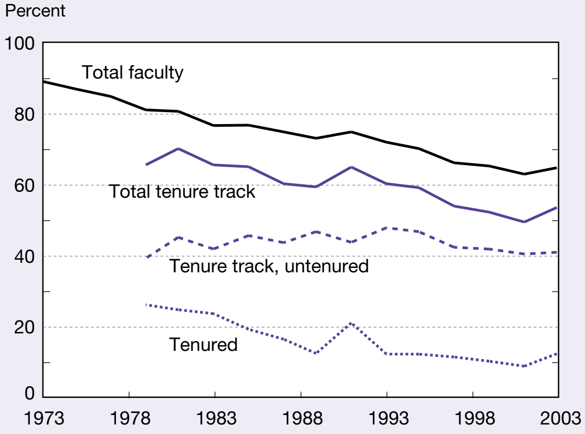
The relative shift toward nonfaculty employment affected almost every major S&E degree field. The share of all doctoral employment held by full-time faculty was lower in 2003 than in 1993 in every broad S&E field. However, in many of these fields, the relative shift toward nonfaculty positions appears to have slowed or leveled off toward the end of this period (appendix table 5-24).

Retirement of S&E Doctoral Workforce

The trend toward relatively fewer full-time faculty and relatively more full-time nonfaculty and postdoc positions is especially noteworthy because academia is approaching a period of increasing retirements. In the 1960s, the number of institutions, students, and faculty in the United States expanded rapidly, bringing many young doctorate holders into academic faculty positions. This growth slowed sharply in the 1970s, and faculty hiring has since continued at a more modest pace. The result is that an increasing number and proportion of faculty are today reaching or nearing retirement age.[24]

The Age Discrimination in Employment Act of 1967 became fully applicable to universities and colleges in 1994.[25] It prohibits the forced retirement of faculty at any age, raising concerns about the potential ramifications of an aging professoriate. Sufficient data have now accumulated to allow examination of some of these concerns. Figure 5-22 shows the age distribution of academic S&E doctorate holders, and figure 5-23 displays the percentage that are age 60 or older.

Figure 5-21
Faculty and tenure-track status of S&E doctorate holders employed in academia 4–7 years after receiving degree: 1973–2003



NOTES: Faculty positions include full, associate, and assistant professors and instructors. Tenure-track data not available for 1973–77.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-25.

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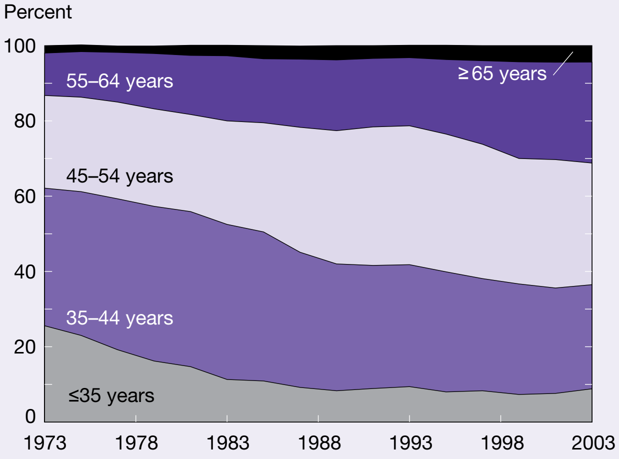
Figure 5-22
Age distribution of academic S&E doctorate holders employed in faculty positions: 1973–2003



NOTE: Faculty employed full time as full, associate, and assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-26.

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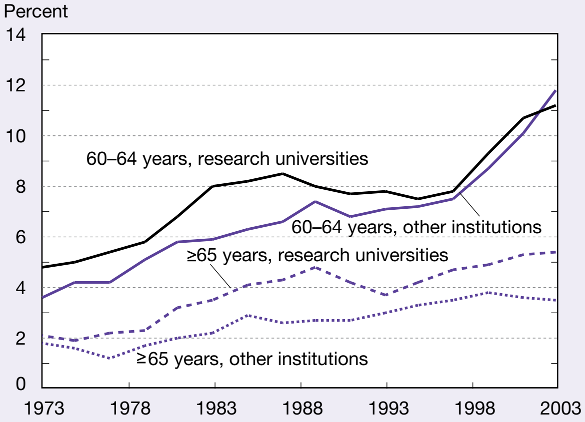
Figure 5-23
Full-time faculty age 60 years and over at research universities and other higher education institutions: 1973–2003



NOTE: Faculty positions include full, associate, and assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-27.

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The data indicate that until recently, individuals age 65 or older (and 70 years or older) constituted a growing share of the S&E doctorate holders employed in academia, suggesting that the Age Discrimination in Employment Act may in fact have had some impact on the age distribution of the professoriate. The data also show that the share of those ages 60–64 was rising well before the act became mandatory, leveled off in the early 1990s, and began to rise again after 1995, reaching just below 12% in 2003. A similar progression can be seen for those age 65 or older, who in 2003 made up over 5% of the research universities' full-time faculty and less than 4% of other institutions' full-time faculty. The employment share of those older than 70 also rose during most of the past three decades, reaching more than 1% of all S&E doctorate holders and all full-time faculty employed in academia in 2001 before dropping to just below 1% for both groups in 2003 (figure 5-23; appendix tables 5-26 and 5-27).

Increasing Role of Women and Minority Groups

Women and underrepresented minority groups constitute a pool of potential scientists and engineers that has not been fully tapped and that, in the case of underrepresented minorities, represents a growing share of U.S. youth, estimated to reach 36% of the college-age population by 2020 (see appendix table 2-4). An accumulating body of research points to the importance of role models and mentoring to student success in mathematics, science, and engineering, especially for women and underrepresented minorities.[26] Thus, the presence of women and underrepresented minorities among faculty on college campuses may be a factor in the recruitment of students from both groups to the S&E fields.

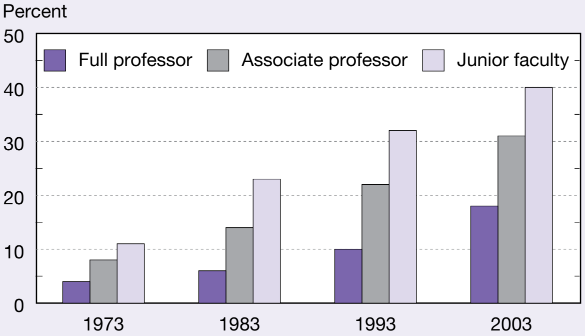
Women

The academic employment of women with S&E doctorates rose sharply between 1973 and 2003, reflecting the increase in the proportion of women among recent S&E doctorate holders. The number of women with S&E doctorates in academia increased more than sevenfold during this period, from 10,700 in 1973 to an estimated 78,500 in 2003 (appendix table 5-28), as compared with about a 70% increase for men. This increase is reflected in the rising share of women among S&E doctorate holders in academic positions. In 2003, women constituted 30% of all academic S&E doctoral employment and just below 28% of full-time faculty, up from 9% and 7%, respectively, in 1973. Women made up a smaller share of total employment at research universities than at other academic institutions at both the beginning and end of this period, with the differential diminishing marginally throughout the period (table 5-7). Compared with male faculty, female faculty remained relatively more heavily concentrated in the life sciences, social sciences, and psychology, with correspondingly lower shares in engineering, the physical sciences, and mathematics.

Women hold a larger share of junior faculty positions than positions at either the associate or full professor rank. However, their share of all three positions rose substantially between 1973 and 2003. In 2003, women constituted 18% of full professors, 31% of associate professors, and 40% of junior faculty, the latter roughly in line with their share of recently earned S&E doctorates[27] (figure 5-24; appendix table 5-28). These trends reflect the recent arrival of significant numbers of women doctorate holders in full-time academic faculty positions.

Figure 5-24

Share of doctoral S&E faculty positions held by women, by rank: Selected years, 1973–2003



NOTE: Junior faculty includes assistant professors and instructors.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Underrepresented Minority Groups

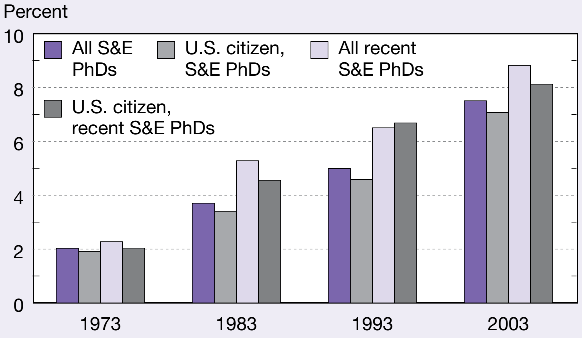
The U.S. Census Bureau's demographic projections have long indicated an increasing prominence of minority groups among future college- and working-age populations. With the exception of Asians/Pacific Islanders, these groups tended to be less likely than whites to earn S&E degrees or work in S&E occupations.[28] Private and governmental groups have sought to broaden the participation of blacks, Hispanics, and American Indians/Alaska Natives in these fields, with many programs targeting their advanced training through the doctorate level.

The absolute rate of conferral of S&E doctorates on members of underrepresented minority groups has increased, as has academic employment; but taken together, blacks, Hispanics, and American Indians/Alaska Natives remain a small percentage of the S&E doctorate holders employed in academia (appendix table 5-29). Because the increases in hiring come from a very small base, these groups constituted only about 8% of both total academic employment and full-time faculty positions in 2003, up from about 2% in 1973. Underrepresented minorities constituted a smaller share of total employment at research universities than at other academic institutions throughout this period (table 5-7). However, among recent doctorate holders, they represented almost 9% of total academic employment and nearly 12% of full-time faculty positions.

These trends are similar for all underrepresented minorities and for those who are U.S. citizens (figure 5-25). Compared with whites, blacks tended to be relatively concentrated in the social sciences and psychology and relatively less

Figure 5-25

Share of underrepresented minorities among S&E doctorate holders employed in academia, by citizenship status and years since degree: Selected years, 1973–2003



NOTES: Denominator always refers to set of individuals defined in legend. Underrepresented minorities include blacks, Hispanics, and American Indians/Alaska Natives. Recent doctorate holders earned degrees within 3 years of survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Table 5-7

Female and minority S&E doctorate holders employed in academia, by Carnegie institution type: Selected years, 1973–2003

(Percent)

Group and institution type	1973	1983	1993	2003
Female				
Research universities	7.4	13.7	20.2	29.1
Other academic institutions	11.2	16.4	23.8	31.6
Underrepresented minority				
Research universities	1.3	3.0	4.1	6.8
Other academic institutions	2.9	4.5	6.0	8.9
Asian/Pacific Islander				
Research universities	4.7	7.4	11.3	15.1
Other academic institutions	3.8	6.0	8.0	11.7

NOTES: Institutions designated by 1994 Carnegie classification code. For more information on these institutional categories, see Carnegie Foundation for the Advancement of Teaching, *A Classification of Institutions of Higher Education*, Princeton University Press (1994), and chapter 2 sidebar, "Carnegie Classification of Academic Institutions." Underrepresented minority includes blacks, Hispanics, and American Indians/Alaska Natives.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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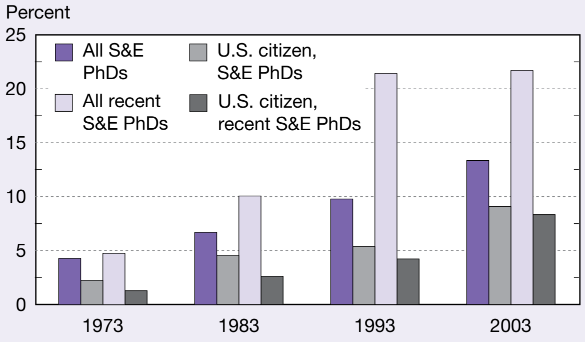
represented in the physical sciences; the earth, atmospheric, and ocean sciences; mathematics; and the life sciences. The field distribution of Hispanic degree holders is similar to that of white degree holders.

Asians/Pacific Islanders

Asians/Pacific Islanders more than tripled their employment share in the S&E academic doctoral workforce between 1973 and 2003, increasing from 4% to 13% (appendix table 5-29). However, a distinction needs to be made between those who are U.S. citizens and those who are not because the latter group constituted close to 40% of this group's doctorate holders in the academic S&E workforce in 2003.[29] The employment share of Asians/Pacific Islanders who are U.S. citizens grew from about 2% of the total academic S&E doctoral workforce in 1973 to just above 9% in 2003, a magnitude of growth similar to that of underrepresented minorities (figure 5-26). Asians/Pacific Islanders, whether or not they are U.S. citizens, represent a larger percentage of total employment at research universities than at other academic institutions (table 5-7). Limiting the analysis to recent S&E doctorate holders leads to even more dramatic differences between Asians/Pacific Islanders who are U.S. citizens and those who are not. Whereas the Asian/Pacific Islander share of all recent S&E doctorate holders employed in academia rose from 5% in 1973 to almost 22% in 2003, the share of those who are U.S. citizens increased from 1% to 8% (figure 5-26).

Compared with whites, Asians/Pacific Islanders as a whole are more heavily represented in engineering and computer sciences and represented at very low levels in psychology and social sciences. This finding holds both for U.S. citizens and for all Asians/Pacific Islanders. In 2003, Asians/Pacific Islanders constituted 29% of academic doctoral computer scientists and more than 23% of engineers (appendix table 5-29)

Figure 5-26
Share of Asians/Pacific Islanders among S&E doctorate holders employed in academia, by citizenship status and years since degree: Selected years, 1973–2003



NOTES: Denominator always refers to set of individuals defined in legend. Recent doctorate holders earned degrees within 3 years of survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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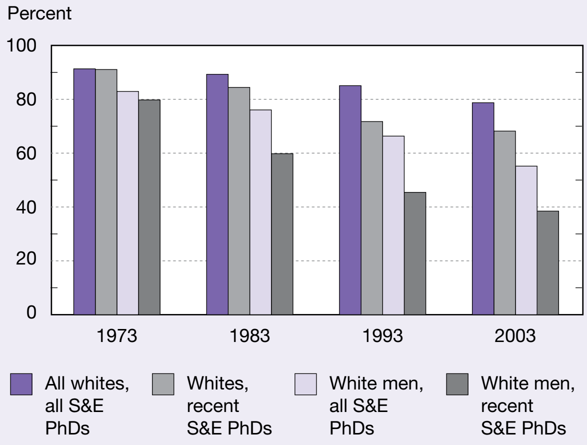
Whites

The relative prominence of whites, particularly white males, in the academic S&E doctoral workforce diminished between 1973 and 2003 (figure 5-27). In 2003, whites constituted 79% of the academic doctoral S&E workforce, compared with 91% in 1973 (table 5-8; appendix table 5-29). The share of white males declined from about 83% to about 55% during this period. The decline in the shares of whites and white males who recently received their doctorates was even greater, from 91% to 68% and from 80% to 38%, respectively. Part of the decline is due to the increasing roles played by women, underrepresented minorities, and Asians/Pacific Islanders. However, the decline in share is not the whole story. During the 1990s, the absolute number of white males in the academic doctoral S&E workforce who recently received their doctorates was virtually unchanged.

Foreign-Born S&E Doctorate Holders

An increasing number and share (23%) of S&E doctorate holders who earned U.S. degrees and are employed at U.S. universities and colleges are foreign born (appendix table 5-30). Like other sectors of the economy, academia has long relied extensively on foreign talent among its faculty, students, and other professional employees. This reliance increased fairly steadily between 1973 and 2003. Figure 5-28 divides holders of U.S. S&E doctorates employed in

Figure 5-27
Share of all whites and white men among S&E doctorate holders employed in academia, by years since degree: Selected years, 1973–2003



NOTE: Recent doctorate holders earned degrees within 3 years of survey.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Table 5-8
White and white male S&E doctorate holders employed in academia, by years since degree: Selected years, 1973–2003

	1973		1983		1993		2003	
Group	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent
All S&E doctorate holders	118.0	100	176.3	100	213.8	100	258.3	100
White	107.7	91	157.4	89	181.8	85	203.3	79
Male	97.8	83	134.1	76	141.8	66	142.5	55
Recent S&E doctorate holders	25.0	100	20.5	100	25.1	100	30.3	100
White	22.8	91	17.3	84	18.0	72	20.7	68
Male	20.0	80	12.3	60	11.4	45	11.7	39

NOTE: Recent doctorate holders earned their degrees within 3 years of survey year.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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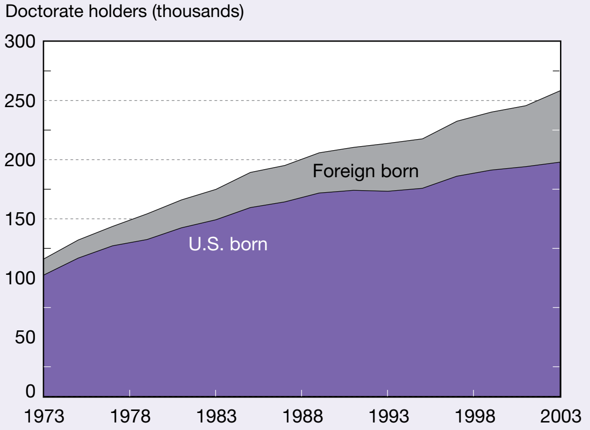
academic institutions into native-born and foreign-born individuals.[30] However, in addition to foreign-born individuals who hold S&E doctorates from U.S. institutions, U.S. universities and colleges also employ a substantial number of foreign-born holders of S&E doctorates awarded by foreign universities. Preliminary estimates from the 2003 National Survey of College Graduates indicate there are approximately 36,000 in the latter group, which would increase the share of foreign-born doctoral-level scientists and engineers employed at U.S. universities and colleges to closer to 33%. The following discussion is based on holders of U.S. doctorates only unless otherwise noted. More information on foreign-born doctorate holders working in the United States can be found in chapter 3.

Employment in higher education of foreign-born S&E doctorate holders has increased continuously, both in number and share, since the late 1970s. Academic employment of foreign-born S&E doctorate holders rose from an average of about 11% of the total in 1973 to 23% in 2003, with some fields, especially computer sciences (44%) and engineering (40%), reaching considerably higher proportions. In 2003, the overall percentage of foreign-born postdocs with S&E doctorates was 43%. The percentage in the physical sciences was 57% and in engineering, 63% (appendix table 5-30).[31]

Figure 5-28
Academically employed U.S. S&E doctorate holders, by birthplace: 1973–2003



SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-30.

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Size of Academic Research Workforce

The interconnectedness of research, teaching, and public service in academia makes it difficult to measure the size of the academic research workforce precisely.[32] For example, a researcher may be doing full-time research in a lab and report research as his or her only activity but mentor several graduate students, which many consider a form of teaching even though no classroom instruction is involved. Two estimates of the number of academic doctoral researchers are presented here: (1) a count of those who report that research is their primary work activity and (2) a higher count of those who report that research is either their primary or secondary work activity.[33]

Postdocs and those in nonfaculty positions are included in both estimates.[34] To provide a more complete measure of the number of individuals involved in research at academic institutions, a lower bound estimate of the number of full-time graduate students who support the academic research enterprise is included, based on those whose primary mechanism of support is a research assistantship (RA). This estimate excludes graduate students who rely on fellowships, traineeships, or teaching assistantships for their primary means of support as well as the nearly 40% who are primarily self-supporting. Many of these students are also likely to be involved in research activities during the course of their graduate education.[35]

Research as Primary Work Activity

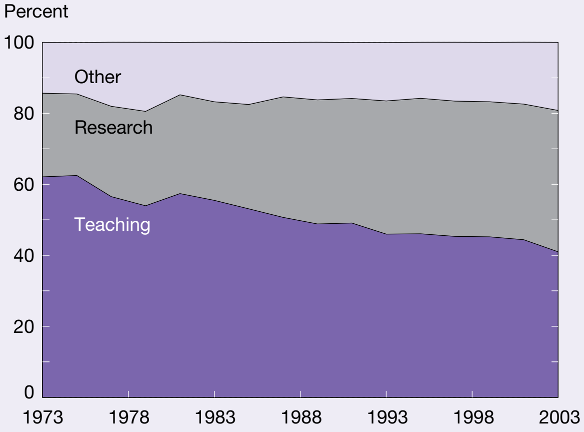
The growth of academic researchers with S&E doctorates who report research as their primary work activity has been substantial, from 27,800 in 1973 to 102,900 in 2003 (appendix table 5-31). During this period, the number of those with teaching as their primary activity increased much less rapidly, from 73,300 to 105,900. Figure 5-29 displays the resulting shifting proportions in the academic workforce. After many years of increase, the proportion of those reporting research as their primary activity began to level off in the mid-1990s, although it increased again in 2003. The drop in the proportion of those reporting teaching as their primary activity has been fairly continuous since the early 1990s.

The different disciplines have distinct patterns of relative emphasis on research, but the shapes of the overall trends are roughly the same. The life sciences stand out, with a much higher share identifying research as their primary activity and, correspondingly, a much lower share reporting teaching as their primary activity. Conversely, mathematics and the social sciences had the largest shares identifying teaching as their primary activity and the lowest shares reporting research as their primary activity (figure 5-30).

Research as Either Primary or Secondary Work Activity

The number of academic S&E doctorate holders reporting research as their primary or secondary work activity also showed greater growth than the number reporting teaching as their primary or secondary activity. The former group increased from 82,300 in 1973 to 178,700 in 2003, whereas the latter group increased from 94,900 to 160,000 (appendix table 5-32).[36]

Figure 5-29
Primary work activity of S&E doctorate holders employed in academia: 1973–2003



NOTE: Research includes basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-31.

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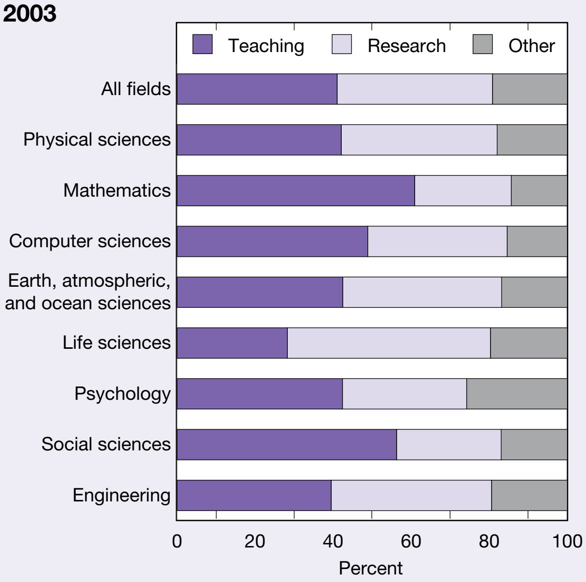
Figure 5-30
Primary work activity of academic S&E doctorate holders employed in academia, by degree field: 2003



NOTE: Research includes basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-31.

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The life sciences accounted for much of this trend, with researchers growing from 26,000 to 65,100 and teachers from about the same base (25,300) to 43,500. The other fields generally included fewer researchers than teachers in the 1970s and early 1980s, but this pattern reversed after that time in the physical sciences; the earth, atmospheric, and ocean sciences; and engineering.

Graduate Research Assistants

The close coupling of advanced training with hands-on research experience is a key strength of U.S. graduate education. To the count of S&E doctoral researchers for whom research is a primary or secondary work activity can be added an estimate of the number of S&E graduate students who are active in research. Among the almost 400,000 full-time S&E graduate students in 2003, many contributed significantly to the conduct of academic research.

Graduate RAs were the primary means of support for more than one-fourth of these students. Table 5-9, which shows the distribution of all full-time S&E graduate students and graduate research assistants (full-time graduate students whose primary mechanism of support is an RA) by field between 1973 and 2003, demonstrates that the number of research assistants has grown considerably faster than graduate enrollment, both overall and in most fields. In both graduate enrollment and the distribution of RAs, there was a shift away from the physical sciences and social sciences and into the life sciences, computer sciences, and engineering. In engineering and the

Table 5-9
Full-time S&E graduate students and graduate research assistants at universities and colleges, by degree field: Selected years, 1973–2003

	1973		1983		1993		2003	
Group and degree field	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent
Graduate students	161.6	100	252.0	100	329.6	100	398.0	100
Physical sciences	21.1	13	25.2	10	30.6	9	30.4	8
Mathematics	10.3	6	11.0	4	14.5	4	14.6	4
Computer sciences	2.9	2	10.6	4	17.4	5	30.9	8
Earth, atmospheric, and ocean sciences	7.8	5	12.0	5	11.3	3	11.5	3
Life sciences	40.6	25	69.2	28	91.6	28	123.2	31
Psychology	15.2	9	26.6	11	34.8	11	35.8	9
Social sciences	32.4	20	43.5	17	55.6	17	61.3	15
Engineering	31.3	19	53.9	21	73.8	22	90.4	23
Graduate research assistants	35.9	100	54.9	100	90.2	100	114.3	100
Physical sciences	6.3	18	9.1	17	12.3	14	13.5	12
Mathematics	0.7	2	0.8	2	1.4	2	1.8	2
Computer sciences	0.7	2	1.4	3	3.8	4	7.5	7
Earth, atmospheric, and ocean sciences	2.6	7	3.5	6	4.7	5	4.6	4
Life sciences	9.4	26	16.5	30	28.0	31	35.5	31
Psychology	1.9	5	3.0	5	4.6	5	5.6	5
Social sciences	4.0	11	5.0	9	7.4	8	8.4	7
Engineering	10.4	29	15.6	28	28.0	31	37.4	33

NOTES: Graduate research assistants are full-time graduate students with research assistantships as primary mechanism of support. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering.

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physical sciences, the proportion of RAs was high relative to graduate enrollment. In the life sciences, the proportion of RAs relative to enrollment was more balanced, possibly reflecting the heavier reliance of these fields on postdoctoral researchers.

Adding graduate research assistants to the count of S&E doctoral researchers for whom research is either the primary or secondary activity yields a more complete lower bound measure of the number of individuals involved in academic research. As noted above, many more graduate students than those with an RA as their primary mechanism of support are carrying out research activities. In addition, more departments are involving undergraduate students in research. With these caveats, the estimated number of academic researchers in 2003 was approximately 293,000 (figure 5-31; appendix table 5-33). It is worth noting that in both computer sciences and engineering, the number of graduate research assistants exceeded the number of doctoral researchers.

Deployment of Academic Research Workforce

This section discusses the distribution of the academic research workforce across types of institutions, positions, and fields. It also examines differences in research intensity by looking at S&E doctorate holders involved in research activities relative to all S&E doctorate holders employed in academia.

Distribution Across Types of Academic Institutions

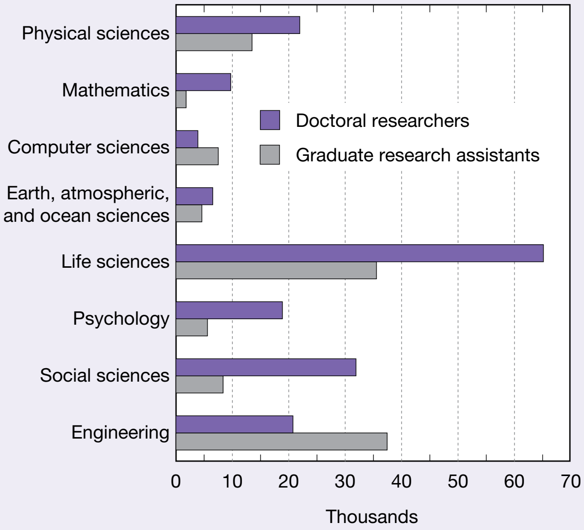
The majority of the research workforce is concentrated in the research universities. In 2003, the research universities employed 49% of all S&E doctorate holders in academic positions, 57% of those reporting research as their primary or secondary activity, and 71% of those reporting research as their primary activity, as well as 80% of S&E graduate students for whom an RA was the primary means of support (appendix table 5-34).

Over the years, however, the research universities' shares of both S&E doctorate holders reporting research as their primary or secondary activity and of graduate research assistants have declined. Table 5-10 provides a long-term overview of the changes in these institutional distributions. These changes are occurring at the same time that research universities' shares of total and federal expenditures for academic research are decreasing. Both trends indicate a growing research presence at institutions not traditionally classified as research universities.

Distribution Across Academic Positions

A pool of academic researchers outside the regular faculty ranks has grown over the years, as shown by the distribution of S&E doctorate holders reporting research as their primary or secondary activity across different types of academic positions:

Figure 5-31
Estimated number of doctoral researchers and graduate research assistants in academia, by degree field: 2003



NOTES: Doctoral researchers are those whose primary or secondary work activity is basic or applied research, development, or design. Graduate research assistants are full-time graduate students with research assistantships as primary mechanism of support.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients; and Survey of Graduate Students and Postdoctorates in Science and Engineering, special tabulations. See appendix table 5-33.

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faculty, postdoctoral fellows, and all other types of appointments (table 5-11; appendix table 5-35). The faculty share of researchers declined from about 88% in 1973 to about 77% in 2003 (approximately the same as the faculty share of all academic employment). For those reporting research as their primary activity, however, the faculty share changed little during this period. The overall decline in faculty share was offset by increases in the shares for both postdocs and those in other nonfaculty positions. Although there have been shifts in the shares of both postdocs and those in other nonfaculty positions during the 30-year period, their respective shares show little difference at the beginning and end of the period. For both those who report research as their primary or secondary activity and those who report it as their primary activity, most of the distributional change across types of academic positions occurred by the mid-1990s.

Distribution Across S&E Fields

Table 5-12 indicates that the distribution across fields of total academic S&E doctoral employment and those who report research as their primary or secondary activity are quite similar. However, the distribution of those who report research as their primary activity differs considerably from the other two distributions in several fields. Notably, it is greater in the life sciences and smaller in mathematics and the social sciences.

Table 5-10
S&E doctorate holders and graduate research assistants employed in academia, by Carnegie institution type: 1973–2003
(Percent distribution)

Group and institution type	1973–83	1983–93	1993–2003
All employed S&E doctorate holders	100.0	100.0	100.0
Research universities	53.7	53.4	50.0
Doctorate-granting institutions	11.5	11.4	11.0
Comprehensive institutions	18.0	18.5	18.3
Other	16.8	16.8	20.7
Researchers	100.0	100.0	100.0
Research universities	64.8	62.2	57.8
Doctorate-granting institutions	10.9	11.2	11.3
Comprehensive institutions	12.4	13.9	14.5
Other	11.9	12.8	16.4
Graduate research assistants	100.0	100.0	100.0
Research universities	87.5	84.0	80.4
Doctorate-granting institutions	9.3	10.1	11.8
Comprehensive institutions	2.2	3.5	4.9
Other	1.0	2.4	2.9

NOTES: Researchers are those reporting research as primary or secondary work activity. Graduate research assistants are full-time graduate students with research assistantships as primary mechanism of support. Institutions designated by 1994 Carnegie classification code. For information on these institutional categories, see chapter 2 sidebar, "Carnegie Classification of Academic Institutions." Freestanding schools of engineering and technology included under comprehensive institutions. "Other" includes freestanding medical schools, 4-year colleges, specialized institutions, and institutions without Carnegie code. Detail may not add to total because of rounding.

SOURCES: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations; and Survey of Graduate Students and Postdoctorates in Science and Engineering, special tabulations. See appendix table 5-34.

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Table 5-11

S&E doctorate holders employed in academia, by involvement in research and position: Selected years, 1973–2003

Involvement in research and position	1973	1983	1993	2003
	Thousands			
All academic employment	118.0	176.1	213.8	258.3
Research as primary or secondary activity	82.3	104.7	150.1	178.7
Research as primary activity	27.8	48.9	80.2	102.9
	Percent distribution			
All academic employment	100.0	100.0	100.0	100.0
Full-time faculty	87.6	84.3	80.6	75.2
Postdocs	3.5	4.7	6.2	6.1
Other full- and part-time positions	8.9	11.0	13.1	18.7
Research as primary or secondary activity	100.0	100.0	100.0	100.0
Full-time faculty	87.5	83.0	81.1	76.5
Postdocs	4.9	7.1	8.9	8.6
Other full- and part-time positions	7.6	9.9	10.0	14.9
Research as primary activity	100.0	100.0	100.0	100.0
Full-time faculty	71.3	68.7	70.9	69.5
Postdocs	13.8	14.5	15.8	13.7
Other full- and part-time positions	14.9	16.6	13.3	16.8

NOTES: Research includes basic or applied research, development, and design. Full-time faculty includes full, associate, and assistant professors plus instructors. Other full- and part-time positions include full-time nonfaculty such as research associates, adjunct positions, lecturers, administrative positions, and part-time positions of all kinds. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-35.

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Table 5-12

S&E doctorate holders employed in academia, by degree field and involvement in research: 2003

(Percent distribution)

		Involvement in research	
Degree field	All academic employment	Primary/ secondary activity	Primary activity
All fields	100.0	100.0	100.0
Physical sciences	12.2	12.3	12.2
Mathematics	6.0	5.4	3.7
Computer sciences	2.0	2.2	1.8
Earth, atmospheric, and ocean sciences	3.4	3.7	3.5
Life sciences	34.5	36.4	45.1
Psychology	12.1	10.6	9.7
Social sciences	18.8	17.9	12.7
Engineering	10.9	11.6	11.3

NOTES: Research includes basic or applied research, development, and design. Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-36.

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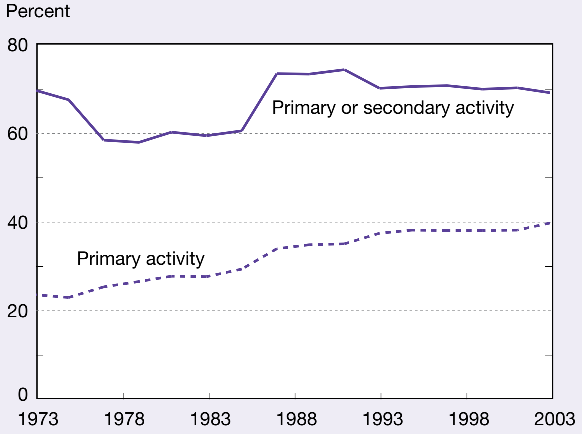
Research Intensity of Academic Institutions

The number of academic S&E doctorate holders reporting research as their primary or secondary activity relative to all S&E doctoral employment declined between 1975 and 1977; was relatively constant at about 60% from the mid-1970s to the mid-1980s, when R&D funds grew relatively slowly; then rose again in 1987 to about 74%; dropped to about 70% in 1993; and remained relatively constant at that level until 2003 (figure 5-32; appendix table 5-36). On the other hand, the corresponding proportion of S&E doctorate holders in academia who reported research as their primary activity experienced a long-term upward trend from the mid-1970s through 2003, increasing from about 23% of total employment to about 40%. The latter trend is fairly similar for each of the broad S&E fields except the computer sciences, which is a new field relative to the others (table 5-13). These data may indicate a growing emphasis on the research function in academia. However, since the two researcher measures

Figure 5-32
S&E doctorate holders employed in academia, by involvement in research: 1973–2003



NOTE: Percent refers to S&E doctorate holders involved in basic or applied research, development, or design as percentage of all S&E doctorate holders.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-35.

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tell somewhat different stories, the reader is cautioned that they are suggestive rather than definitive.

Government Support of Academic Doctoral Researchers

Academic researchers rely on the federal government for a significant share (about 60%) of their overall research support. The institutional and field distributions of these funds are well documented, but little is known about their distribution among researchers. This section presents data from reports by S&E doctorate holders in academia about the presence or absence of federal support for their work. However, nothing is known about the magnitude of these funds to individual researchers. (See sidebar, "Interpreting Federal Support Data.")

Appendix table 5-37 shows the percentage of academic S&E doctorate holders who received federal support for their work during the period 1973–2003, broken out by field. The analysis examines the overall pool of doctoral S&E researchers as well as young doctorate holders, for whom support may be especially critical in establishing a productive research career.

Academic Scientists and Engineers Who Receive Federal Support

In 2003, 46% of all S&E doctorate holders in academia, 72% of those for whom research was the primary activity, and 36% of those for whom research was a secondary activity reported federal government support (appendix table 5-37). As table 5-14 shows, for S&E as a whole and for each of the broad fields, the likelihood of receiving federal support in 2003 was either the same as in 1991 or lower.

The percentage of S&E doctorate holders in academia who received federal support differed greatly across the S&E fields. In 2003, this percentage ranged from about 63% in the earth, atmospheric, and ocean sciences to about 22% in the social sciences (table 5-14; appendix table 5-37).

Full-time faculty received federal funding less frequently than other full-time doctoral employees, who, in turn, were supported less frequently than postdocs. In 2003, about 45% of full-time faculty, 48% of other full-time employees, and 78% of postdocs received federal support. As indicated earlier, these proportions were lower than those in 1991, but dropped less for full-time faculty than for postdocs or other full-time positions (appendix table 5-37). (See sidebar, "Has Academic R&D Shifted Toward More Applied Work?)

Table 5-13
S&E doctorate holders employed in academia who reported research as primary activity, by degree field: Selected years, 1973–2003
(Percent)

Degree field	1973	1983	1993	2003
All fields	23.6	27.8	37.5	39.8
Physical sciences	26.8	30.7	42.0	40.0
Mathematics	15.5	15.5	21.9	24.8
Computer sciences	NA	40.0	36.0	35.7
Earth, atmospheric, and ocean sciences	20.1	31.2	42.2	40.7
Life sciences	36.7	44.3	52.8	52.0
Psychology	16.7	21.0	26.8	31.8
Social sciences	12.1	12.6	24.1	26.8
Engineering	16.6	21.5	34.2	41.1

NA = not available

NOTE: Research includes basic or applied research, development, and design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-36.

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Table 5-14
S&E doctorate holders employed in academia who reported receiving federal support in previous year, by degree field: Selected years, 1973–2003
(Percent)

Degree field	1973	1983	1991[a]	2003
All fields	44.5	44.3	50.3	46.0
Physical sciences	47.7	50.9	56.6	54.8
Mathematics	26.9	30.1	34.5	30.6
Computer sciences	NA	44.6	49.4	48.9
Earth, atmospheric, and ocean sciences	45.0	54.5	66.2	62.6
Life sciences	59.3	60.0	65.5	57.3
Psychology	37.5	30.1	34.7	34.6
Social sciences	25.5	23.7	28.4	21.9
Engineering	53.5	54.7	63.2	57.3

NA = not available

[a] 1991 used because 1993 not comparable with other years and understates degree of federal support by asking whether work performed during week of April 15 was supported by government. In other years, question pertains to work conducted over course of year.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-37.

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Interpreting Federal Support Data

Interpretation of the data on federal support of academic researchers is complicated by a technical difficulty. Between 1993 and 1997, respondents to the Survey of Doctorate Recipients were asked whether work performed during the week of April 15 was supported by the federal government; in most other survey years, the reference was to the entire preceding year; in 1985, it was to 1 month. However, as these data series clearly illustrate, the volume of academic research activity is not uniform over the entire academic year. A 1-week (or 1-month) reference period seriously understates the number of researchers supported over an entire year. Thus, the numbers for 1985 and 1993–97 cannot be compared directly with results for the earlier years or those from the 1999 through 2003 surveys, which again used an entire reference year.

The discussion here compares data for 1999 through 2003 with the earlier series. All calculations express the proportion of those with federal support relative to the number responding to this question. The reader is cautioned that, given the nature of these data, the trends discussed are broadly suggestive rather than definitive. The reader also is reminded that the trends in the proportion of all academic researchers supported by federal funds occurred against a background of rising overall numbers of academic researchers.

Federal Support of Young S&E Doctorate Holders in Academia

Early receipt of federal support is viewed as critical to launching a promising academic research career. The pattern of support for young researchers is similar to that of the overall academic S&E doctoral workforce: those in full-time faculty positions were less likely to receive federal support than those in postdoc or other full-time positions. However, for each of these three positions, the percentage reporting federal support in 2003 was higher for the overall academic S&E doctoral workforce than for those with recently earned doctorates (i.e., within 3 years of the survey) (appendix tables 5-37 and 5-38).

In 2003, about 49% of those with recently earned doctorates received federal support, with 30% of those in full-time faculty positions and 45% of those in other full-time positions receiving support, compared with about 78% of those in postdoc positions (appendix table 5-38). As with all academic doctoral holders, younger researchers were less likely to report federal support in 2003 than in 1991. The share of postdocs receiving federal support was relatively low (below 70%) in some fields (e.g., the social sciences, psychology, and mathematics) and high (80% or more) in others (e.g., computer sciences; the life sciences; and the earth, atmospheric, and ocean sciences).

In 2003, young academics who had gained some experience (i.e., those who had received their doctorate 4–7 years earlier) were considerably more likely to receive federal support than those with recently earned doctorates. However, this group also was less likely to receive support in 2003 than in 1991 (table 5-15; appendix tables 5-37 and 5-38). It should be pointed out that the data provide no information about whether an individual reporting federal support is being supported as a principal investigator on a research project or is participating in a more dependent status rather than as an independent researcher.

Table 5-15

S&E doctorate holders employed in academia 4–7 years after receiving degree who reported receiving federal support in previous year, by degree field: Selected years, 1973–2003

(Percent)

Degree field	1973	1983	1991[a]	2003
All fields	44.6	50.1	57.4	47.6
Physical sciences	44.8	66.2	67.2	51.1
Mathematics	29.0	39.8	28.3	33.9
Computer sciences	NA	43.5	66.2	43.6
Earth, atmospheric, and ocean sciences	53.4	64.5	76.6	67.9
Life sciences	59.7	67.1	70.6	57.2
Psychology	37.8	32.3	38.8	37.5
Social sciences	29.0	28.1	36.6	22.7
Engineering	50.7	64.3	73.2	64.3

NA = not available

[a] 1991 used because 1993 not comparable with other years and understates degree of federal support by asking whether work performed during week of April 15 was supported by government. In other years, question pertains to work conducted over course of year.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations. See appendix table 5-38.

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Has Academic R&D Shifted Toward More Applied Work?

Emphasis on exploiting the intellectual property that results from the conduct of academic research is growing. (See section “Outputs of S&E Research: Articles and Patents.”) Some observers believe that emphasis has been accompanied by a shift away from basic research and toward the pursuit of more utilitarian, problem-oriented questions.

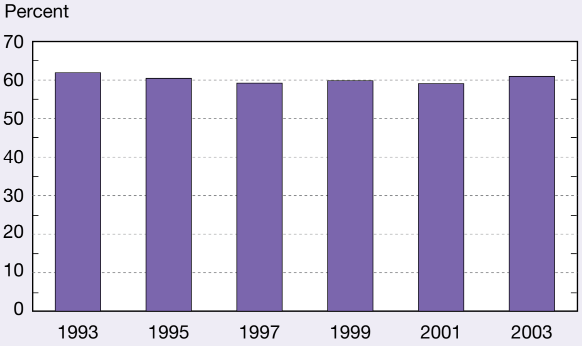
We lack definitive data to address this issue. As indicated earlier in the chapter, it is often difficult to make clear distinctions among basic research, applied research, and development. Sometimes basic and applied research can be complementary to each other and embodied in the same research. Some academic researchers may obtain ideas for basic research from their applied research activities.

Two indicators, however, bear on this issue. One is the share of all academic R&D expenditures directed to basic research. Appendix table 5-1 does not show any decline in the basic research share since the late 1980s. The second indicator is the response to a question S&E doctorate holders in academia were asked about their primary or secondary work activities, including four R&D functions: basic research, applied research, design, and development.

As figure 5-33 shows, for those employed in academia who reported research as their primary activity, involvement in basic research declined slightly between 1993 and 2003, from 62% to 61%—probably not statistically significant. The available data, although limited, provide little evidence to date of a shift toward more applied work.

Figure 5-33

S&E doctorate holders with primary activity research whose primary activity is basic research: Selected years, 1993–2003



NOTE: S&E doctorate holders involved in research include those whose primary work activity is basic or applied research, development, or design.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Survey of Doctorate Recipients, special tabulations.

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Outputs of S&E Research: Articles and Patents

The products of academic research include trained personnel and advances in knowledge. Trained personnel are discussed earlier in this chapter and also in chapter 2. This section presents data on two knowledge-related additional indicators of scientific research output: scientific articles authored worldwide and patents received by U.S. academic institutions. In addition, it presents data on citations to previous scientific work contained in articles and patents.

Articles, patents, and citations provide indicators, albeit imprecise ones, of scientific output, the content and priorities of scientific research, the institutional and intellectual linkages within the research community, and the ties between scientific research and practical application. Data on articles, patents, and citations, used judiciously, enable meaningful comparisons across institutional sectors, scientific disciplines, and nations in terms of scientific output and research capacity.

Articles are one key measure of output for scientific research because publication has been the norm for disseminating and validating research results and is crucial for career advancement in most scientific fields.[37] Data on the authorship of articles also provide information on the extent of research collaboration and on patterns and trends in collaboration across institutional, disciplinary, and national boundaries.

Citations provide another measure of scientific productivity by indicating how influential previous research has been. Patterns in citations can show links within and across institutional boundaries. Citations to scientific articles in U.S. patents provide indications of the degree to which technological innovations rely on scientific research.

The number of patents issued to U.S. universities is another indicator of the output of academic science. In addition, it is an indicator of the relationship between academic research and commercial application of new technologies.

For a discussion of the nature of the data used in this section, see sidebar, “Data and Terminology.”

Data and Terminology

The article counts, coauthorship data, and citations discussed in this section are based on S&E articles, notes, and reviews published in a slowly expanding set of the world’s most influential scientific and technical journals tracked by Thompson ISI, formerly the Institute for Scientific Information, in the *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI)* (http://www.isinet.com/products/citation/). These data are not strictly comparable to those presented in editions prior to the 2004 edition of *Science and Engineering Indicators,* which were based on a fixed *SCI/SSCI* journal set. The advantage of the “expanding” set of journals is that it better reflects the current mix of influential journals and articles. However, changes over time in journal coverage can inflate article counts. The number of journals covered by *SCI/SSCI* was 4,458 in 1988, 4,601 in 1993, 5,084 in 1998, and 5,315 in 2003.

Field designations for articles in the journals tracked by *SCI/SSCI* are determined by the classification of the journal in which an article appears. Journals are assigned to 1 of 134 fine fields, which are grouped into 12 broad fields, on the basis of the patterns of a journal’s citations (appendix table 5-39).

SCI and *SSCI* give good coverage of a core set of internationally recognized peer-reviewed scientific journals, albeit with some English-language bias. The coverage extends to electronic journals, including print journals with electronic versions and electronic-only journals. Journals of regional or local importance may not be covered, which may be salient for the categories of engineering and technology, psychology, the social sciences, the health sciences, and the professional fields, as well as for nations with a small or applied science base.

Author as used here means *departmental or institutional author.* Articles are attributed to countries and sectors by the author’s institutional affiliation at the time of publication. If the institutional affiliation of an article’s author is not listed, the article would not be attributed to an institutional author and would not be included in the article counts in this chapter. Likewise, *coauthorship* refers to institutional coauthorship: a paper is considered coauthored only if its authors have different institutional affiliations or are from separate departments of the same institution. Multiple authors from the same department of an institution are considered as one institutional author. The same logic applies to cross-sectoral and international collaboration.

Two methods of counting articles based on attribution are used: fractional and whole counts. In *fractional counting*, credit for an article with authors from more than one institution or country is divided among the collaborating institutions or countries based on the proportion of their participating departments or institutions. In *whole counting*, each collaborating institution or country receives one credit for its participation in the article. Fractional counting is generally used for article and citation counts, and whole counting for coauthorship data.

All data presented here derive from the Science Indicators database prepared for the National Science Foundation by ipIQ, Inc., formerly CHI Research, Inc. The database excludes all letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

Worldwide Trends in Article Output

The number of scientific articles cataloged in the internationally recognized peer-reviewed set of S&E journals covered by the *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI)* grew from approximately 466,000 in 1988 to nearly 700,000 in 2003, an increase of 50% (figure 5-34). The growth of publications reflects both an expansion in the number of journals covered by the *SCI* and *SSCI* databases and an increase in the number of articles per journal during this period. The number of articles in a fixed set of journals that have been tracked by *SCI/SSCI* since 1985 has also risen, indicating that the number of articles per issue and/or issues per journal grew during this period. Other S&E journal databases that have broader and/or more specialized coverage of scientific fields in general show an increasing number of publications (appendix table 5-40).

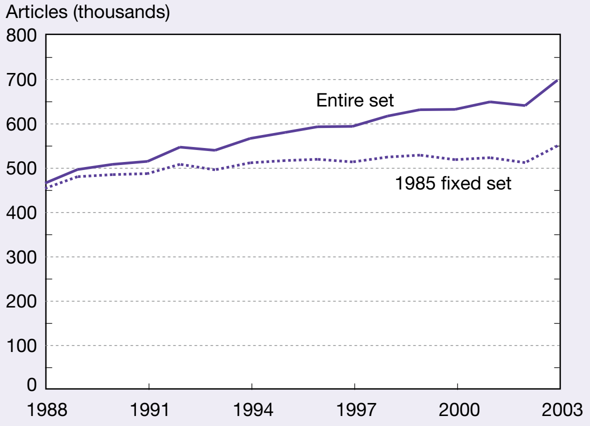
Data on article authorship by country provide an indication of the knowledge and research capacity of regions and countries. Data by scientific discipline provide a comparative measure of national research priorities.

Trends in Three Major Publishing Regions

Strong increases in S&E articles published in the European Union (EU)-15,[38] Japan, and the East Asia-4 countries and economies (China, including Hong Kong, Singapore, South Korea, and Taiwan) accounted for 69% of the increase in world output between 1988 and 2003 (figure 5-35; appendix table 5-41).

The article output of the EU-15 grew by more than 60% between 1988 and 2003, surpassing that of the United States in 1998 (figure 5-35; appendix table 5-41). This rate of growth slowed, however, starting in the mid-1990s (figure 5-36). Japan's article output rose at a slightly faster pace than that of the EU-15 (figure 5-36), resulting in gain in output of nearly 75% between 1988 and 2003. Japan's growth rate, however, slowed in the latter half of the 1990s in a pattern similar to that of the EU-15.

Figure 5-34
Worldwide S&E article output of selected journal sets: 1988–2003



NOTES: Entire journal set consists of journals tracked by *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI)* that increase over time. 1985 fixed journal set is fixed number of journals reflecting *SCI* and *SSCI* journal coverage in 1985.

SOURCES: Thomson ISI, *SCI* and *SSCI,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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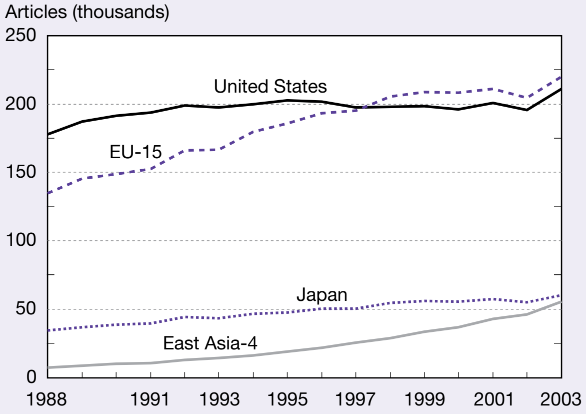
Figure 5-35
S&E article output, by major S&E publishing region or country/economy: 1988–2003



EU = European Union

NOTES: Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-41.

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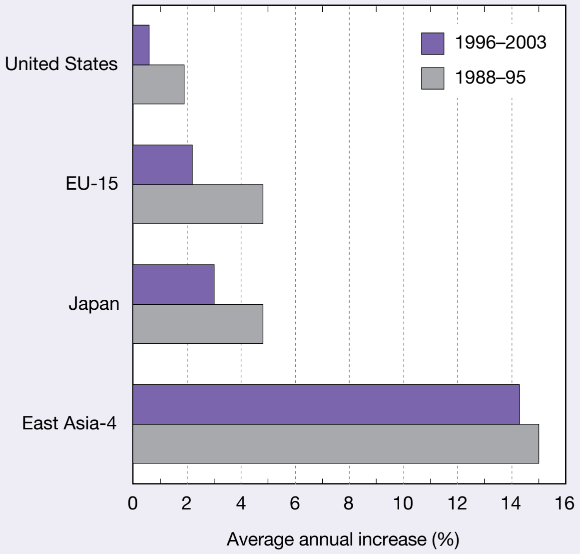
The article output of the East Asia-4 rose more than sevenfold, pushing its share of the world's S&E articles from below 2% in 1988 to 8% in 2003 (figure 5-35; table 5-16). By country, the increase in output was 6-fold in China and the Taiwan economy, 7-fold in Singapore, and nearly 18-fold in South Korea, up from only 771 articles in 1988 to more than 13,000 15 years later (appendix table 5-41). S&E article growth in China and South Korea resulted in these two countries becoming the 6th- and 12th-ranked countries by share of world article output in 2003 (appendix table 5-42). On a per capita basis, the article output levels of Singapore, South Korea, and Taiwan were comparable to those of other advanced countries (appendix table 5-43). China's per capita article output, however, was far below this level.

Trends in U.S. Article Output

In the United States, growth in article output was markedly slower than in the other major S&E publishing regions and remained essentially flat between 1992 and 2003, despite continued growth of research inputs.[39] Neither the full dimensions of this trend, a reversal of three prior decades of consistent growth, nor the reasons for it are clear (See sidebar, "Exploring Recent Trends in U.S. Publications Output.") As a result

Figure 5-36
Growth in S&E article output, by major S&E publishing region or country/economy: 1988–2003



EU = European Union

NOTES: Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each publishing country/economy receives fractional credit on basis of proportion of its participating institutions. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-41.

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of nearly stagnant U.S. output and continued growth in other parts of the world, the U.S. share of all articles fell from 38% to 30% between 1988 and 2003 (table 5-16).

This phenomenon of stagnant output is not limited to the United States. Five mature industrial countries with significant article outputs (Canada, the United Kingdom, France, the Netherlands, and Sweden) experienced a similar flattening starting in the latter half of the 1990s (figure 5-37).

The U.S. growth trend varied by field (table 5-17). Biomedical research and physics, which together accounted for one-quarter of U.S. article output in 2003, declined between 1996 and 2003. During the same period, articles in clinical medicine, which accounted for 31% of all output in 2003, increased at the same average rate (0.6%) as overall annual output. The six remaining fields that constituted 44% of U.S. articles in 2003—biology, chemistry, the earth and space sciences, engineering and technology, mathematics, and the social and behavioral sciences[40]—had higher than average growth during 1996–2003.

Trends in Other Regions and Countries

Output increased sharply in many regions and countries between 1988 and 2003, but there were notable exceptions (appendix table 5-41):

Exploring Recent Trends in U.S. Publications Output

Publication of research results in the form of articles in peer-reviewed journals is the norm for contributing to the knowledge base in nearly all scientific disciplines. It has become customary to track the number of peer-reviewed articles as one, albeit imperfect, indicator of research output. In recent years, international use of this and related indicators has become widespread, as countries seek to assess their relative performance.

The recent flattening in the output of U.S. S&E publications contrasts with continued increases in real R&D expenditures and number of researchers. The reasons for these divergent trends remain unclear. To explore what factors may be implicated in this development, the National Science Foundation (NSF) undertook a special study that addresses the following questions:

- What key trends affected the scientific publishing industry in the 1990s?
- Is the apparent change in output trends real or an artifact of the indicators used?
- What are the characteristics of the change in the trend?
- What factors may contribute to it, and what evidence exists about whether and how these factors are involved?

The project analyzes key developments in scientific publishing, with particular focus on the 1990s, to establish the broad outlines of the environment in which scientific publishing in the United States is taking place. In addition to an in-depth look at indicators of U.S. output trends, it includes methodological research that focuses directly on measurement approaches, journal coverage, and other technical considerations that affect indicators of publications output.

Work is underway to determine where in the U.S. research system these trend changes are found; what institutional, demographic, funding, or other factors may be contributing to them; in what fields these changes are occurring; and how different changes relate to one another.

A primary focus of the study is the U.S. academic system, which publishes the majority of U.S. articles and conducts most U.S. research. NSF's Science Resources Statistics (SRS) division has been conducting a multivariate study to examine quantifiable relationships among publication outputs, resource inputs, and institutional characteristics of the top 200 academic R&D institutions. Selected data from this study are presented in this chapter. SRS staff have also conducted interviews with faculty and administrators at nine top-tier research universities to better understand how the publishing and research environment may be changing and help put quantifiable data in context. The results of the study are expected to be published in a series of special reports.

Table 5-16

Share of world S&E article output, by major publishing region or country/economy: 1988, 1996, and 2003

(Percent distribution)

Region or country/economy	1988	1996	2003
Worldwide	100.0	100.0	100.0
EU-15	28.8	32.6	31.5
United States	38.1	34.0	30.3
Japan	7.4	8.5	8.6
East Asia-4	1.5	3.7	7.9
Other OECD	10.9	11.1	11.2
All other countries	13.2	10.2	10.5

EU = European Union; OECD = Organisation for Economic Co-operation and Development

NOTES: Region/country/economy ranked by share in 2003. Shares based on articles credited to institutional address of region/country/economy. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong. Other OECD excludes United States, Japan, and South Korea.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Figure 5-37

Growth of S&E article output, by selected country: 1988–2003

NOTES: Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries, each country receives fractional credit on basis of proportion of its participating institutions.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-41.

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- The S&E article output of Latin America more than tripled.
- The combined output of the Southeast Asian countries of Indonesia, Malaysia, the Philippines, Thailand, and Vietnam nearly tripled.
- The output of the Near East and North Africa more than doubled, albeit from a low base.
- The output of India, the Asian country with the largest S&E article output after Japan and the East Asia-4, began increasing in the mid-1990s after years of stagnation, resulting in a 44% gain during this period.
- The combined output of the Eastern European countries of Bulgaria, the Czech Republic, Hungary, Poland, and Romania followed a similar trend to that of India. Output began increasing in the late 1990s, resulting in a 41% gain during this period.
- In contrast to the Eastern European countries listed above, Russia's output decreased 27% between 1994 and 2003.
- The S&E article output of Sub-Saharan Africa, which accounted for less than 1% of world output in 2003, fell 7% between 1988 and 2003.

Field Distribution of Articles

The publications of the United States, the EU-15, and Japan are dominated by the life sciences (figure 5-38). Other Organisation for Economic Co-operation and Development (OECD) countries also have a similar portfolio (appendix tables 5-44 and 5-45). In the portfolios of the East Asia-4, however, the physical sciences and engineering and technology are more dominant. Among developing countries, the portfolios of countries in the Near East and North Africa (excluding Israel) and Eastern Europe and the former Union of Soviet Socialist Republics (USSR) are similar to those of the East Asia-4. Like the United States, the EU-15, and Japan, Latin America and Sub-Saharan Africa have portfolios dominated by the life sciences (appendix tables 5-44 and 5-45).

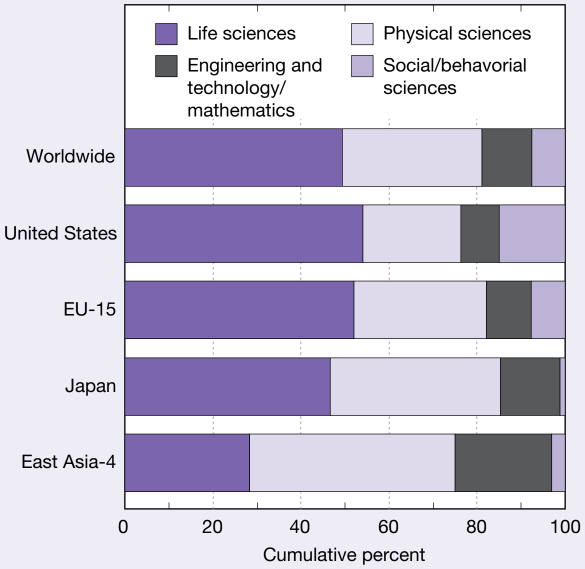
Worldwide Trends in Scientific Collaboration

Patterns in coauthorship of S&E articles are an indicator of how research is organized. Trends toward more frequent coauthorship spanning national, sectoral, and institutional boundaries indicate greater globalization and interdependence in the science community. The rise in scientific collaboration has been driven by several factors:

- The scientific advantages of combining knowledge, perspectives, techniques, and resources that extend beyond a single institution or discipline to advance scientific research
- Lower costs of air travel and telephone calls, which have facilitated collaborative research and conference attendance, which can lead to coauthorship
- The widespread use of new kinds of information technology, including the Internet, e-mail, and high-capacity computer networks that allow researchers to locate collaborators, exchange information, share data files, and even conduct experiments from a distance
- National policies in many countries that encourage institutional or international collaboration and the end of Cold War barriers to collaboration
- The participation of graduate students in study abroad programs

The rise in international collaboration has been driven by intensified collaboration among the major S&E publishing regions: the United States, the EU-15, Japan, and the East Asia-4. Other contributing factors are collaboration between these major publishing regions and the developing world

Figure 5-38
Field distribution of S&E articles, by major S&E publishing region or country/economy: 2003



EU = European Union

NOTES: Regions/countries/economies ranked by share of life sciences. Life sciences consist of clinical medicine, biomedical research, and biology. Biology includes agricultural sciences. Physical sciences consist of chemistry, physics, and earth and space sciences. Social/behavioral sciences consist of social sciences, psychology, health sciences, and professional fields. Engineering/ technology includes computer sciences. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-45.

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Table 5-17
U.S. S&E article output, by field: 1988–2003
(Percent)

Field	Average annual growth 1988–95	Average annual growth 1996–2003	2003 share of article output
All fields	1.9	0.6	100.0
Mathematics	–2.5	2.3	1.8
Earth/space sciences	4.4	2.1	5.9
Biology	–0.2	1.3	6.6
Social/behavioral sciences	1.1	1.3	14.9
Engineering/technology	2.4	1.0	7.0
Chemistry	1.8	0.8	7.5
Clinical medicine	2.1	0.6	31.2
Biomedical research	3.6	–0.2	16.3
Physics	1.4	–0.6	8.8

NOTES: Articles on fractional-count basis, i.e., for articles with collaborating U.S. and foreign institutions, United States receives fractional credit on basis of proportion of its participating institutions. Fields ranked by 1996–2003 growth rate. Social/behavioral sciences consist of psychology, social sciences, health sciences, and professional fields. Engineering/technology includes computer sciences. Biology includes agricultural sciences.

SOURCES: Thomson ISI, *Science Citation Index and Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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and the development of an East Asian area of collaboration centered on Japan and, increasingly, China.

One indicator of increasing collaboration, the average number of author names and addresses on an article, rose between 1988 and 2003 (table 5-18). A second indicator is the distribution of articles by type of authorship: articles authored by a single national institution, articles authored by multiple departments or institutions within a single country, and international articles, which are those with authors from at least two different countries (figure 5-39). Between 1988 and 2003, international articles doubled in share from 8% to 20%, and articles authored by multiple departments or institutions within a single country increased their share from 32% to 39%.

The number of countries collaborating on an article also expanded. In 2003, more than 60 countries had joint authorship with at least 60 nations, compared with 32 in 1996 (figure 5-40; appendix table 5-46). Although international ties have greatly expanded, many countries, particularly in the developing world or those with smaller scientific establishments, tend to concentrate much of their collaboration with a relatively small number of developed countries.

International Collaboration by the United States

U.S. researchers collaborate with counterparts in more countries than do the researchers of any other country. In 2003, U.S. authors collaborated with authors in 172 of the 192 countries that had any internationally coauthored articles in 2003 (appendix table 5-46). Scientific collaboration in the United States increased between 1988 and 2003, particularly international collaboration. The average number of foreign addresses on U.S. scientific articles more than tripled during this period (table 5-18). The share of U.S. articles with international authorship (articles with at least one U.S. address and one address outside the United States)[41] grew the fastest, rising from 10% of all U.S. S&E articles in 1988 to 25% in 2003 (figure 5-41). Such articles became more prevalent in all fields. By field, international collaboration in 2003 was highest in the earth and space sciences, physics, and mathematics, at a rate of more than 35% (figure 5-42). International collaboration rates were much lower in the social sciences, psychology, the health sciences, and the professional fields at 10%–14%.

The U.S. share of the world's internationally coauthored articles fell between 1988 and 2003, however, from 51% to 44% (figure 5-43). Its share of coauthorship on the international articles of the EU-15 and Japan fell from almost 50% in 1988 to below 40% in 2003 (figures 5-44 and 5-45; appendix tables 5-47, 5-48, and 5-49). In turn, the East Asia-4 and the countries of Eastern Europe and the former USSR increased their share with these two regions (appendix tables 5-47 through 5-52). The United States also lost coauthorship share on the international articles of the East Asia-4 as these economies expanded their collaboration with the EU and other countries (figure 5-46). Finally, the U.S. coauthorship share fell in many developing countries (appendix tables 5-50 through 5-55). In India, both the U.S. and the EU-15 shares fell as India increased coauthorship with Japan and the East Asia-4 (appendix tables 5-47 through 5-49). In Latin America, the U.S. share declined from 45% to 37% between 1988 and 2003, and the EU-15 became the largest collaborating region (appendix tables 5-47 through 5-49).

Two regions increased their coauthorship share on U.S. articles: the East Asia-4 and Eastern Europe and the former

Table 5-18

Author names and addresses on S&E articles, by major publishing region or country/economy: 1988, 1996, and 2003

(Average number)

Author names and addresses	Worldwide	United States	EU-15	Japan	East Asia-4
1988					
Names	3.06	2.98	3.33	3.96	3.37
All addresses	1.75	1.78	1.70	1.63	1.63
Foreign addresses	na	0.15	0.19	0.14	0.34
1996					
Names	3.68	3.75	4.17	4.82	4.75
All addresses	2.19	2.11	2.05	1.99	2.07
Foreign addresses	na	0.32	0.35	0.31	0.56
2003					
Names	4.22	4.42	4.81	5.58	5.61
All addresses	2.68	2.44	2.42	2.39	2.30
Foreign addresses	na	0.51	0.52	0.49	0.55

na = not applicable

EU = European Union

NOTES: East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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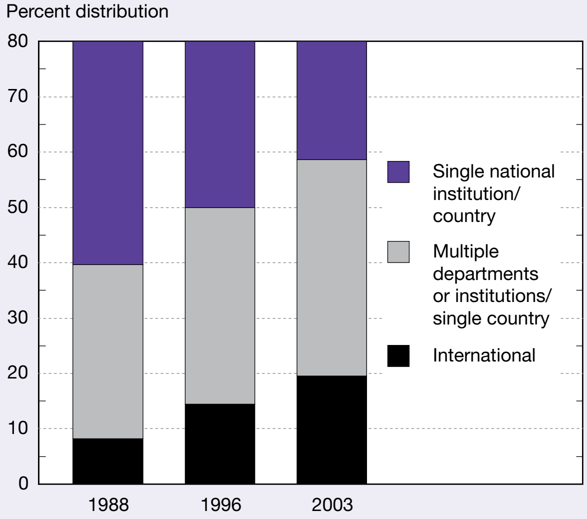
Figure 5-39
Distribution of S&E articles by type of authorship: 1988–2003



NOTES: Single national institution/country articles have one institutional address. Multiple department or institution/single country articles have multiple addresses from a single country, either from a single institution or multiple institutions. International articles have authors from at least two different countries listed on article. Counts of S&E articles worldwide were 466,419 in 1988, 593,568 in 1996, and 698,726 in 2003.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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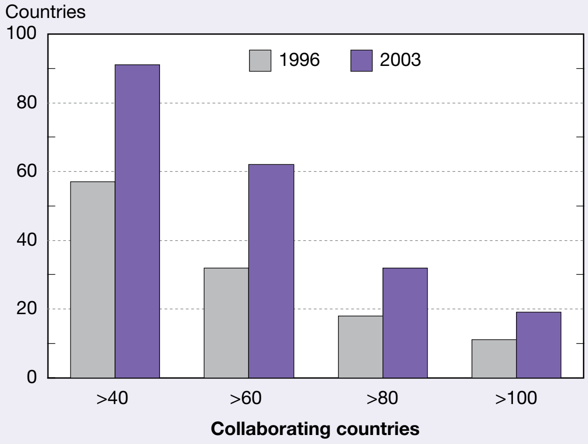
Figure 5-40
Collaborating countries/economies on S&E articles: 1996 and 2003



NOTE: Data are number of countries/economies that have jointly authored articles (based on institutional address) with indicated number of countries/economies.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-46.

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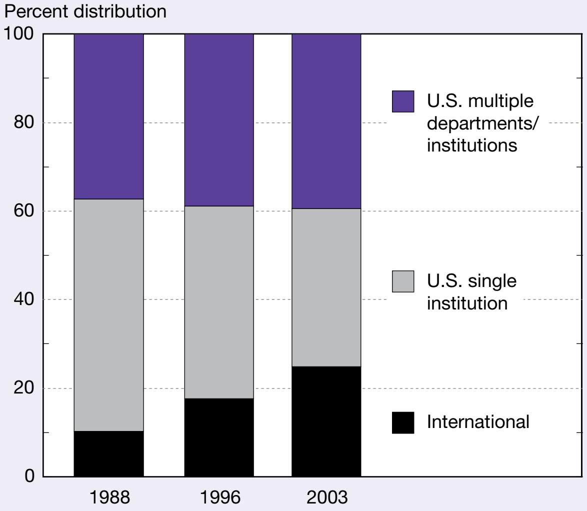
Figure 5-41
U.S. S&E articles, by type of authorship: 1988, 1996, and 2003



NOTES: Domestic multiple department/institution articles are those with more than one listed institutional address from the same institution or multiple U.S. institutions. International articles have at least one collaborating U.S. and foreign institution. Articles on whole count basis, i.e., for article with collaborating U.S. and foreign institutions, the United States is credited one count for its participation (187,225 in 1988, 221,414 in 1996, and 242,397 in 2003).

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-59 and 5-60.

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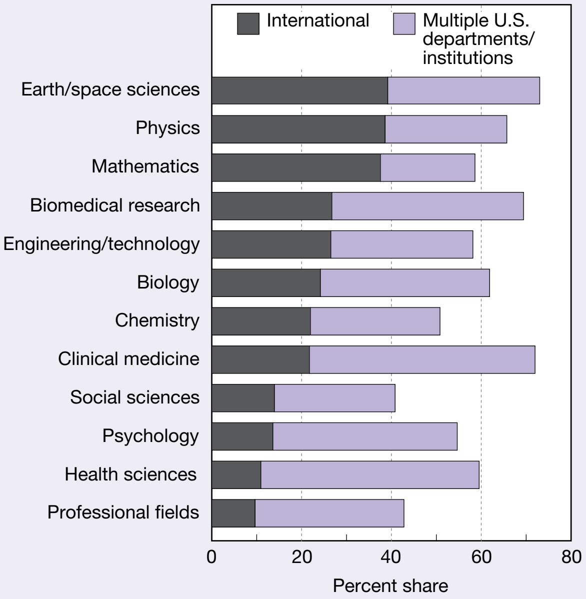
USSR (figure 5-47). The increases were primarily due to China and South Korea in the former group and Russia in the latter. The patterns of international collaboration with the United States also appear to reflect the relationship between the number of U.S. foreign-born doctorate recipients and publications jointly authored by their country of origin and the United States (figure 5-48).[42]

International Collaboration by the EU-15

In the EU-15, articles with at least one coauthor from a non-EU-15 country accounted for 36% of all articles in 2003, up from 17% in 1988 (figure 5-49). The EU-15 countries, many of which had extensive ties during the previous decade, continued to expand their partnerships. There were 10 EU-15 member countries with ties to 100 or more nations in 2003, a clear indicator of this region's extensive scientific collaboration with other nations (appendix table 5-46). Much of the high degree of international collaboration within the EU (as measured by the share of member countries' articles coauthored with other EU-15 countries) reflects the extensive intraregional collaboration centered on France, Germany, Italy, the Netherlands, and the United Kingdom (appendix tables 5-47 through 5-49). The extent of intra-European collaboration reflects proximity, historical ties, and EU programs that encourage collaboration.

Figure 5-42
Extent of multiple authorship on U.S. S&E articles, by field: 2003



NOTES: Number of S&E articles with authors from multiple departments/institutions, including foreign, as share of total S&E articles. Fields ranked by international share. Field volume on whole-count basis, i.e., for articles with collaborating U.S. and foreign institutions, the United States is credited one count. International articles are those with at least one collaborating U.S. and foreign institution. Multiple U.S. department/institution articles are those with multiple U.S. addresses from the same institution or multiple U.S. institutions. Engineering/technology includes computer sciences. Biology includes agricultural sciences.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-59 and 5-60.

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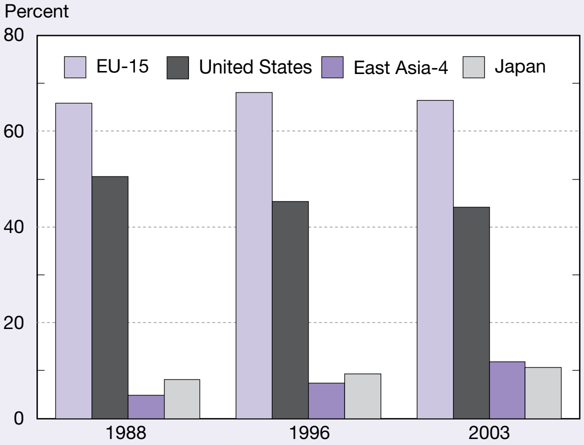
Figure 5-43
Share of international S&E articles, by major S&E publishing region or country/economy: 1988, 1996, and 2003



EU = European Union

NOTES: Articles on whole-count basis, i.e., for articles with collaborating institutions from more than one country/economy, each country/economy is credited one count. International articles are those with at least one collaborating institution from indicated region/country/economy and an institution from outside the region/country/economy (38,190 in 1988, 85,968 in 1996, and 136,577 in 2003). Shares exceed 100% because each selected region/country/economy receives one count for its participation on articles with other selected countries/regions. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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International Collaboration by Japan

In Japan, the share of articles with international coauthors increased from 9% to 22% between 1988 and 2003, as Japan broadened its collaboration with more countries (figure 5-49; appendix table 5-46). Japan's collaboration with the East Asia-4 increased considerably during this period, particularly with China (figure 5-50).

International Collaboration by the East Asia-4

In the economies comprising the East Asia-4, the share of articles with a coauthor outside the region increased slightly during the period 1988–2003 (figure 5-49).[43] The change in collaborative patterns was similar to that in Japan, with a decline in U.S. involvement, as measured by share of articles, an expansion in the number of collaborative partners, and a growing intraregional collaborative network centered in Japan and, increasingly, China (figure 5-50).

Trends in Output and Collaboration Among U.S. Sectors

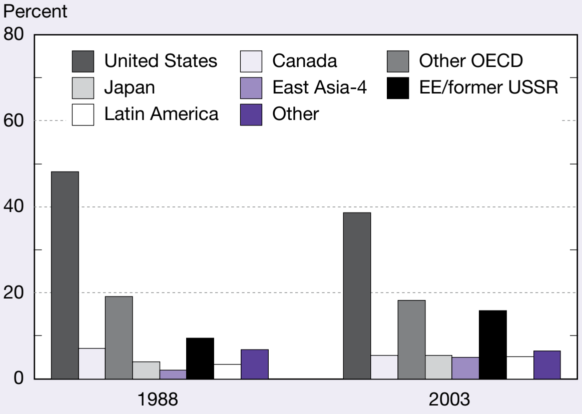
The volume and share of article production by various U.S. institutional sectors (academic, federal and state government, private for profit, and nonprofit) offer a measure of the relative role of these sectors in U.S. research. Coauthorship among these sectors provides an indicator of the integration of U.S. sectors in the U.S. S&E community. Government policies have reinforced collaboration among U.S. sectors by funding research programs that require or encourage collaboration. International collaboration of U.S. sectors is an indicator of the globalization of U.S. sectors in the international S&E community.

Output Trends of U.S. Sectors

The growth in the academic sector, which generates most U.S. publications (74% in 2003), mirrored the overall pattern of U.S. S&E article output (table 5-19). Growth trends did vary, however, among a subset of top 200 academic R&D institutions grouped on the basis of their R&D growth and 1994 Carnegie classification. At institutions that registered higher-than-average R&D growth between 1988 and 2003, the growth in article output was correspondingly

Figure 5-44

Region/country/economy coauthorship share on EU-15 international S&E articles, by selected region/grouping: 1988 and 2003



EE = Eastern Europe; EU = European Union; OECD = Organisation for Economic Co-operation and Development; USSR = Union of Soviet Socialist Republics

NOTES: Coauthorship share is fractional share of region/country/economy on EU-15 international articles (25,179 in 1988, 58,576 in 1996, and 90,779 in 2003). International articles are those with at least one collaborating EU-15 institution and one non-EU-15 institution. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-47, 5-48, and 5-49.

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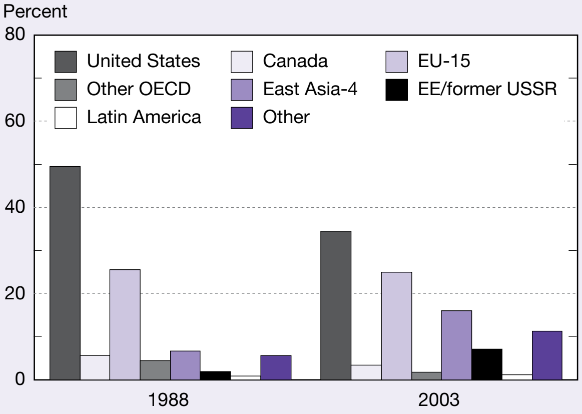
Figure 5-45

Region/country/economy coauthorship share on Japan's international S&E articles, by selected region/grouping: 1988 and 2003



EE = Eastern Europe; EU = European Union; OECD = Organisation for Economic Co-operation and Development; USSR = Union of Soviet Socialist Republics

NOTES: Coauthorship share is fractional share of region/country/economy on Japan's international articles (3,097 in 1988, 7,973 in 1996, and 14,534 in 2003). Japan's international articles are those with at least one collaborating Japanese institution and one non-Japanese institution. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-47, 5-48, and 5-49.

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greater than that of other institutions (table 5-20; appendix table 5-56). By Carnegie class, the S&E article output of private academic institutions, which produce approximately one-third of the articles attributed to the top 200 academic R&D institutions, grew faster than that of public academic institutions between 1988 and 2001 (table 5-21).

The combined article output of nonacademic sectors, which accounted for slightly more than one-quarter of overall U.S. output in 2003, also followed the pattern of overall U.S. S&E article output (table 5-19). The growth trend, however, varied by sector. In the federal government, output declined after 1994, primarily because of a decrease in articles in the life sciences and physics (figure 5-51). The output of the private for-profit sector fell during the 1990s, with significant declines in the fields of chemistry, physics, and engineering and technology. The article output of the nonprofit sector grew nearly 30% between 1988 and 2003 due to an increase in articles in clinical medicine.

Collaboration Among U.S Sectors

Collaboration of the academic sector with other U.S. sectors increased between 1988 and 2003, as measured by the share of coauthored articles (figure 5-52; appendix tables 5-57 and 5-58). Twenty-eight percent of academic articles in 2003 were coauthored with nonacademic authors, up from 22% in 1988. Collaboration among nonacademic sectors also rose during this period (table 5-22; appendix tables 5-57 and 5-58). The federal government and the private for-profit sector each nearly doubled their share of papers coauthored with other U.S. nonacademic sectors, from about 15% in 1988 to nearly 30% in 2003, realizing the highest gains in share of all nonacademic sectors.

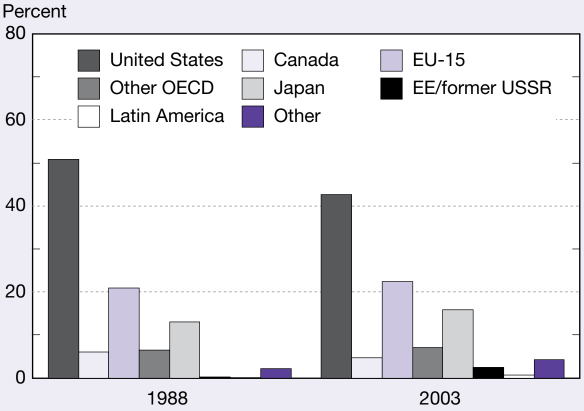
The international collaboration of the U.S. academic sector increased significantly between 1988 and 2003. The share of academic articles with a foreign author increased from 11% to 24% during this period, a change in magnitude similar to the increase in the share of all U.S. articles with a foreign coauthor (figure 5-52; appendix tables 5-59 and 5-60). As measured by the share of articles with coauthors from non-U.S. institutions, the international collaboration of nonacademic sectors more than doubled during this period (table 5-22).

Worldwide Trends in Citation of S&E Articles

Citations in S&E articles generally credit the contribution and influence of previous research to a scientist's own research. Trends in citation patterns by region, country, scientific field, and institutional sector are indicators of the influence of scientific literature across institutional and

Figure 5-46

Region/country/economy coauthorship share on East Asia-4 international S&E articles, by selected region/grouping: 1988 and 2003



EE = Eastern Europe; EU = European Union; OECD = Organisation for Economic Co-operation and Development; USSR = Union of Soviet Socialist Republics

NOTES: Coauthorship share is fractional share of region/country/economy on East Asia-4 international articles (1,824 in 1988, 6,085 in 1996, and 15,110 in 2003). East Asia-4 international articles are those with at least one collaborating East Asia-4 institution and one non-East Asia-4 institution. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-47, 5-48, and 5-49.

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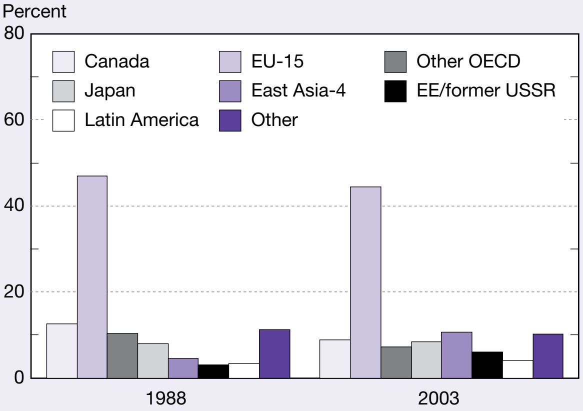
Figure 5-47

Foreign coauthorship on U.S. international S&E articles, by selected region/grouping: 1988 and 2003



EE = Eastern Europe; EU = European Union; OECD = Organisation for Economic Co-operation and Development; USSR = Union of Soviet Socialist Republics

NOTES: Coauthorship share is fractional share of region/country/economy on U.S. international articles (19,294 in 1988, 39,046 in 1996, and 60,180 in 2003). U.S. international articles are those with at least one U.S. author and one non-U.S. author. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-47, 5-48, and 5-49.

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national boundaries.[44] Citations may also indicate the accessibility of scientific research across national boundaries.

The volume of citations worldwide increased from 2.69 million in 1992 to 4.34 million in 2003, an increase of 61% (figure 5-53). During this period, the share of cross-national citations grew from 42% to 48%, another sign of the increasing globalization of science. With widespread use of the Internet and electronic databases, researchers increasingly are accessing scientific literature from around the world. The rate of foreign research citation varied by field in 2003, with higher-than-average shares in biomedical research, physics, and chemistry, and the lowest shares in psychology, the social sciences, the health sciences, and the professional fields (figure 5-54). The fields with the lowest shares of foreign research citation also have lower than average shares of internationally authored articles.

Citation Trends for Three Major Publishing Regions

The EU-15, Japan, and the East Asia-4, the same regions that drove the increase in S&E article output, also drove the increase in volume of citation of scientific literature between 1988 and 2003 (figure 5-55; appendix table 5-61). Citation of EU-15 literature grew by 87% between 1992 and 2003, pushing this region's share of the world's cited literature from 28% to 33% (table 5-23). Citation of Japanese literature also rose substantially, increasing at roughly the same rate as the citation of EU-15 literature. Citation of literature from East Asia-4 authors in China, Singapore, South Korea, and Taiwan rose nearly sevenfold in volume during this period, with the collective share of these countries rising from less than 1% of the world's cited literature in 1992 to 3% in 2003.

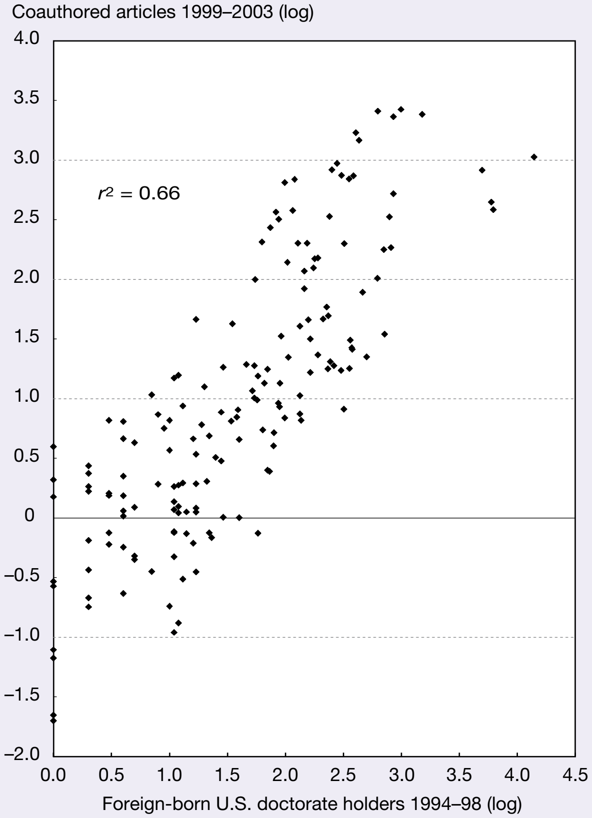
Citation Trends for the United States

The volume of cited U.S. scientific literature grew 32% between 1988 and 2003, less than half the rate of the EU-15 and Japan, and flattened during the late 1990s. This resulted in the U.S. share falling from 52% in 1992 to 42% in 2003 (figure 5-55; table 5-23; appendix table 5-61). This flattening in citation of U.S. literature occurred across almost all fields and mirrored the trend of flat U.S. output of S&E articles during this period (table 5-24). Two fields diverged from this overall trend: Between 1992 and 2003, citations of physics literature fell 19%, paralleling the drop in publications, whereas citations of articles in the earth and space sciences rose more than 80%. Nevertheless, U.S. literature remained the most cited source of foreign S&E literature for the EU-15, Japan, and the East Asia-4.

S&E literature originating in the United States represents a much larger share of the literature cited by U.S. authors than the S&E literature of the three other major publishing

Figure 5-48

Relation of foreign-born U.S. doctorate holders to their country's scientific collaboration with United States: 1994–98 and 1999–2003



SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, Survey of Earned Doctorates, special tablulations.

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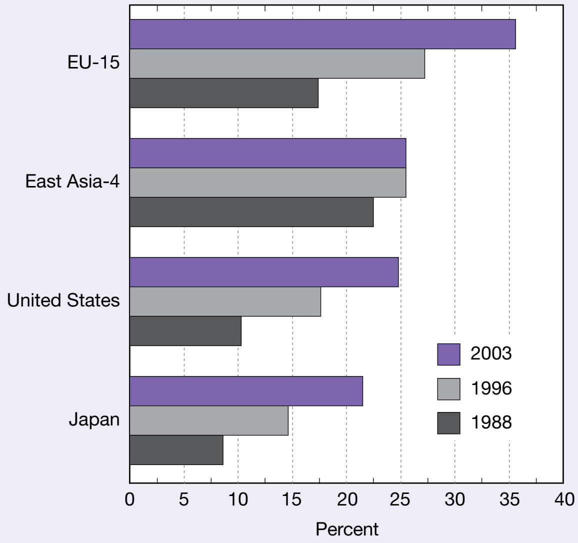
regions represents for each of those regions. In 2003, U.S. literature accounted for 61% of the literature cited by U.S. authors, whereas Japanese literature accounted for only 36% of the literature cited by Japanese authors, the second highest share of domestic citation among the four major publishing regions (figure 5-56). The foreign literature cited the most by the United States in 2003 was that of the EU-15, accounting for a 23% share.

Relative Citation of S&E Literature

An alternative measure, the *relative citation index*, shows the comparative citation intensity of a country or region's research by scientists from the rest of the world.[45] This indicator showed less change in the citation patterns of the four major S&E publishing regions between 1992 and 2003 than simple citation volume. The U.S. relative citation index was considerably higher than that of the other three publishing regions between 1992 and 2003 and remained constant during this period (table 5-25). U.S. relative citation indexes by field also remained stable (appendix table 5-62). The relative citation index of the EU-15 was the second highest, increasing slightly between 1992 and 2003. The relative citation index of the East Asia-4, which was considerably lower than that of the EU-15, also increased slightly during this period. The relative citation index of Japan was considerably lower than those of the United States and the EU-15 and showed little change.

Figure 5-49

Share of international S&E articles, by major S&E publishing region or country/economy: 1988, 1996, and 2003



EU = European Union

NOTES: Region/country/economy ranked by 2003 share. International articles are those with at least one collaborating institution from indicated region/country/economy and one institution from outside the region/country/economy. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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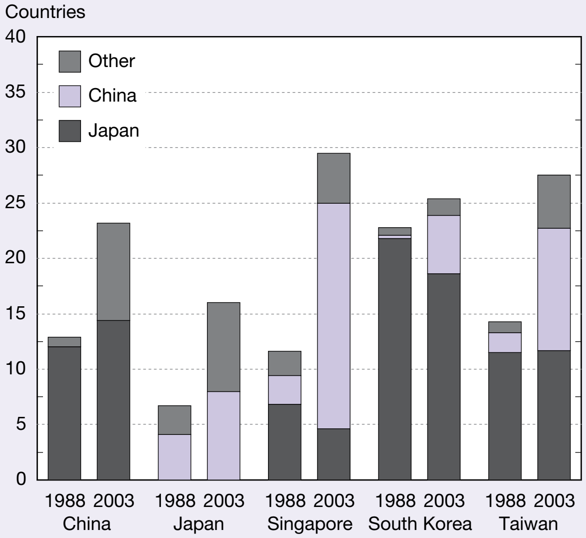
Trends in Highly Cited S&E Literature

A country or region's share of highly cited S&E articles, as ranked by frequency of citation, provides an indicator of its position in highly influential research. Between 1992 and 2003, the U.S. share of the top 5% of cited S&E articles fell from 59% to 50%, whereas the shares of the other three publishing regions, particularly the EU-15, rose (figure 5-57; appendix table 5-63). The decline in the U.S. share of all cited S&E articles during this period, which occurred at roughly the same magnitude as the decline in highly cited articles, suggests that the erosion of the U.S. citation share was not confined to less influential research.

The trend during this period for the United States and the other three major publishing regions was similar when measured by share of citations in highly cited journals (the

Figure 5-50
Intraregional collaboration on international S&E articles of selected East Asian countries/ economies: 1988 and 2003



NOTES: International S&E articles are those with at least one collaborating institution from an indicated East Asian country/ economy. Share of country authorship is fractional share of a given East Asian country/economy on designated East Asian country/ economy's international S&E articles. Other consists of Singapore, South Korea, and Taiwan.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-47, 5-48, and 5-49.

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Table 5-20
Growth of S&E article output of top 200 academic R&D institutions, by R&D growth quartile: 1988–2003
(Percent)

	Average annual growth rate		
Quartile	1988–2003	1988–95	1996–2003
Total	1.5	2.1	1.0
Quartile 1	2.5	3.5	1.3
Quartile 2	2.0	2.5	1.5
Quartile 3	0.9	1.1	0.6
Quartile 4	1.0	1.8	0.4

NOTES: Top 200 academic R&D institutions assigned to four quartiles, ranging from quartile 1, consisting of institutions with highest growth rate, to quartile 4, consisting of those with lowest growth rate. Four institutions excluded because of incomplete R&D data. Articles on fractional-count basis, i.e., for articles with multiple collaborating top-200 institutions and/or other institutions, each top 200 institution receives fractional credit on basis of proportion of its participating institutions.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-56.

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journals being ranked by the average number of citations to articles published in each journal) (appendix table 5-64). Despite the declining U.S. share of influential research, U.S. shares of highly cited articles and journals continued to be high relative to the United States' overall share of citations. In comparison, the other three publishing regions' shares of highly cited articles and journals were equal to or less than their overall citation shares.

Citations in U.S. Patents to S&E Literature

U.S. patents cite previous source material to help meet the application criteria of the U.S. Patent and Trademark Office (U.S. PTO).[46] Although existing patents are cited the most often, U.S. patents have increasingly cited scientific articles. This growth in citation of S&E literature, referenced by scientific field, technology class of the patent, and the nationality of the inventor and cited literature, provides an indicator of the link between research and practical application.[47]

Table 5-19
S&E article output, by academic and nonacademic sector: Selected years, 1988–2003
(Thousands)

Sector	1988	1991	1993	1995	1997	1999	2001	2003
All sectors	177.7	194.0	197.4	202.9	197.5	198.5	200.9	211.2
Academic	127.3	139.3	142.3	146.5	144.6	145.5	147.8	156.6
Top 200 academic R&D institutions	116.9	127.8	130.4	134.6	132.4	133.3	135.7	143.6
Other	10.4	11.5	11.9	11.9	12.2	12.1	12.1	13.1
Nonacademic	50.4	54.7	55.1	56.4	52.9	53.1	53.1	54.6

NOTES: Top 200 U.S. academic R&D institutions determined by total R&D expenditures between 1988 and 2001. Articles on fractional-count basis, i.e., for articles with collaborating institutions from more than one sector, each sector receives fractional credit on basis of proportion of its participating institutions. Nonacademic consists of private for profit, private nonprofit, federal government, state and local government, federally funded research and development centers, and other.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-56.

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Table 5-21
Growth in S&E article output of top 200 academic R&D institutions, by type of control and Carnegie classification: 1988–2001
(Percent)

Type of control and Carnegie classification	Average annual growth rate 1988–2001	1988–95	1996–2001
All 200	1.5	2.5	0.2
Public	1.3	2.3	–0.0
Research 1	1.1	2.2	–0.2
Research 2	1.4	2.1	0.7
Medical	2.6	3.8	0.1
All others	2.6	2.8	1.1
Private	2.0	2.7	0.7
Research 1	2.0	2.5	0.8
Research 2	0.7	0.8	0.9
Medical	2.9	4.3	0.8
All others	2.0	2.7	0.7

NOTES: Top 200 academic R&D institutions assigned according to 1994 Carnegie classification. Articles on fractional-count basis, i.e., for articles with multiple collaborating top-200 institutions and/or other institutions, each top 200 institution receives fractional credit on basis of proportion of its participating institutions.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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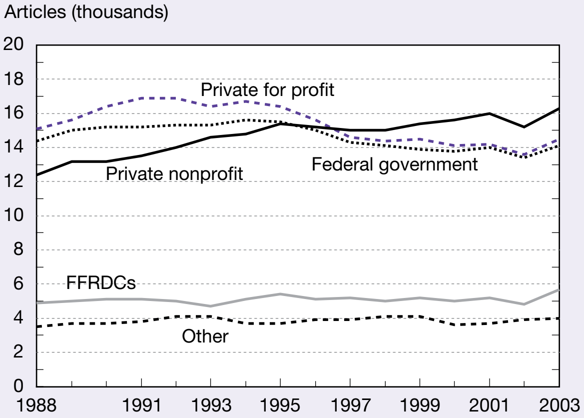
Figure 5-51
S&E article output of U.S. nonacademic sectors: 1988–2003



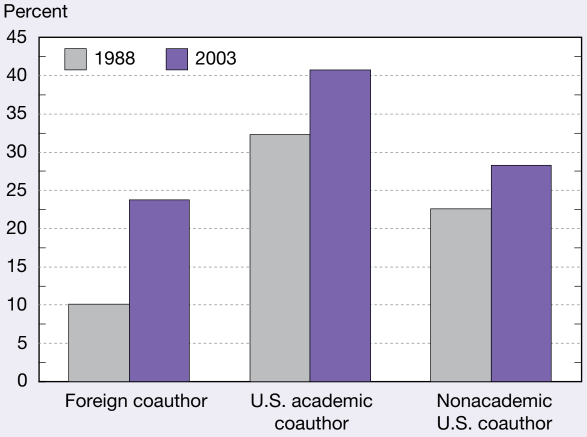
FFRDC = federally funded research and development center

NOTES: Articles on fractional-count basis, i.e., for articles with collaborating institutions from more than one sector, each sector receives fractional credit on basis of proportion of its participating institutions. Other consists of state and local government and unknown.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

Science and Engineering Indicators 2006

Figure 5-52
U.S. sector and foreign coauthorship share of U.S. academic S&E articles: 1988 and 2003



NOTE: Articles on whole-count basis, i.e., for articles with collaborating institutions from multiple sectors and/or foreign institutions, each sector and/or foreign country receives one count for participation by its institution(s).

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-57, 5-58, 5-59, and 5-60.

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U.S. patent citations to S&E articles on an average per patent and volume basis rose rapidly between 1987 and 1998, when growth slowed (figure 5-58; appendix table 5-65).[48] The growth in citations through much of the period 1987–2002 was driven, in part, by increased patenting of research-driven products and processes, primarily in the life sciences, and changes in the practices and procedures of the U.S. PTO. (See next section, "Patents Awarded to U.S. Universities.")

The rapid growth in the volume of citations throughout much of the period 1995–2004 was centered in articles authored by the academic sector (61% share of total citations in 2004), primarily in the fields of biomedical research and clinical medicine (appendix table 5-66). Academic-authored articles in these two fields accounted for 41% of the increase in total citations across all fields between 1995 and 2004. Citations to academic articles in physics and engineering and technology also increased during this period and became a larger share (40% to 61% in physics and 44% to 53% in engineering and technology). This increase coincided with a decline in the share of patent citations of articles authored by the industrial (private for-profit) sector in these fields and the stagnating publications output in that sector.

Industry was the next most widely cited sector (21% share in 2004), with articles in the fields of physics and engineering and technology prominently represented. Industry, however, lost share in these two fields between 1995 and 2004 (appendix table 5-66).

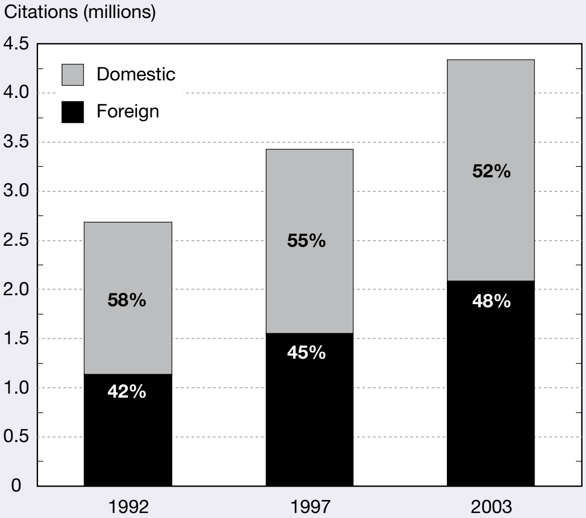
The bulk of U.S. patents citing scientific literature were issued to U.S. inventors, who accounted for 65% of these patents in 2003, a share disproportionately higher than the 51% of all U.S. patents issued to U.S. inventors (table 5-26). The three other major S&E publishing regions accounted for most of the patents citing S&E literature issued to non-U.S. inventors. These regions' shares of patents citing S&E literature, however, were equal to or less than their shares of all U.S. patents.

Examination of the share of cited literature of each of the four major publishing regions, adjusted for their respective share of the world output of scientific literature (relative citation index) and excluding citation of the literature of the inventor's country or region suggests that, relative to its share of publications, U.S. scientific literature is cited in U.S. patents more frequently than that of the EU-15, Japan, or the East Asia-4 (table 5-27). Thus, in both patents and scientific articles, U.S. literature is cited more frequently than would be expected based on the U.S. share of world article output.

Patents Awarded to U.S. Universities

The results of academic S&E research increasingly extend beyond articles in S&E journals to patent protection of research-derived inventions.[49] Patents are an indicator of the efforts of academic institutions to protect the intellectual property derived from their inventions, technology transfer,[50] and industry-university collaboration. The rise of patents received by U.S. universities attests to the increasingly important role of academic institutions in creating and

Figure 5-53
Worldwide citations of S&E literature: 1992, 1997, and 2003



NOTES: Citations are references to articles, notes, and reviews in journals covered by *Science Citation Index* (SCI) and *Social Sciences Citation Index* (SSCI). Citation counts based on a 3-year window with 2-year lag; e.g., citations for 2001 are references made in articles published in 2001 to articles published in 1997–99. Numbers refer to share of citations to foreign S&E literature. Foreign citations are references originating outside author's country. Domestic citations are references that originate from same country as article author.

SOURCES: Thomson ISI, SCI and SSCI, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-61.

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Table 5-22
Coauthorship share of nonacademic sectors: 1988 and 2003
(Percent)

Sector and year	Total articles	U.S. sector Academic	U.S. sector Nonacademic	Non-U.S. Institutions
FFRDCs				
1988	7,171	39.2	14.6	16.3
2003	10,975	51.9	21.6	37.0
Federal government				
1988	22,044	48.2	16.2	9.9
2003	27,020	57.3	27.5	24.4
State/local government				
1988	3,670	60.4	30.3	5.4
2003	4,112	68.1	50.5	12.7
Private for profit				
1988	20,221	31.1	15.2	8.2
2003	25,584	47.3	27.4	24.1
Private nonprofit				
1988	19,473	54.0	15.5	9.1
2003	29,957	59.0	24.5	22.3

FFRDC = federally funded research and development center

NOTE: Articles on whole-count basis, i.e., for articles with collaborating institutions from more than one U.S. sector and/or non-U.S. sector, each sector with at least one participating institution is credited one count.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix tables 5-57, 5-58, 5-59, and 5-60.

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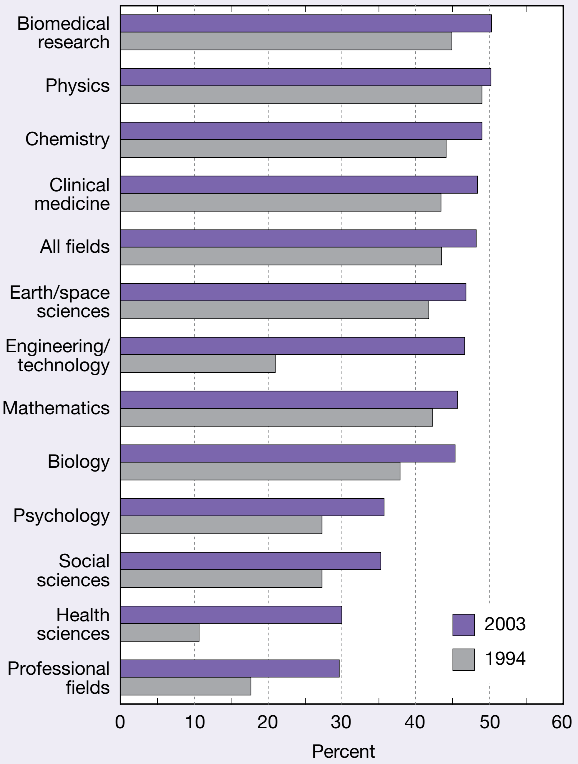
Figure 5-54
Foreign scientific literature cited in worldwide scientific articles: 1994 and 2003



NOTES: Citations are references to scientific articles in journals covered by *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI).* Citation counts based on a 3-year period with 2-year lag (e.g., citations for 2000 are references made in articles published in 1996–98). Fields ranked by 2001 share. Engineering/ technology includes computer sciences. Biology includes agricultural sciences.

SOURCES: Thomson ISI, *SCI* and *SSCI,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-62.

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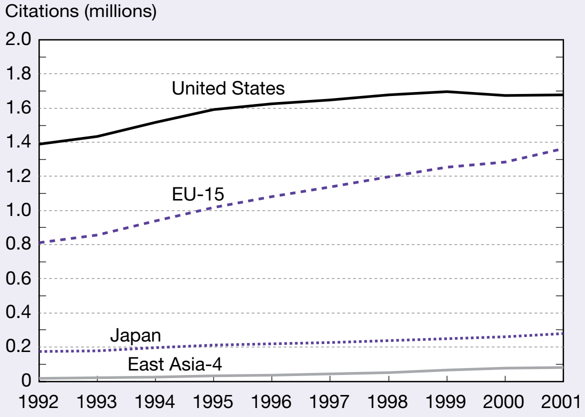
Figure 5-55
Citations of S&E literature, by region or country/ economy: 1988–2003



EU = European Union

NOTES: Citations on fractional-count basis, i.e., for cited articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-61.

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Table 5-23
Share of world scientific literature cited in S&E articles, by major S&E publishing region or country/economy: 1992, 1997, and 2003
(Percent distribution)

Region or country/economy	1992	1997	2003
Worldwide	100.0	100.0	100.0
United States	51.7	48.1	42.4
EU-15	28.1	30.8	32.5
Other OECD	9.2	9.5	9.8
Japan	6.5	6.6	7.3
East Asia-4	0.7	1.3	3.3
All other countries	3.8	3.8	4.6

EU = European Union; OECD = Organisation for Economic Co-operation and Development.

NOTES: Region/country/economy ranked by share in 2001. Share based on publication counts from set of journals classified and covered by *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI)* and on institutional address of article. Citations on fractional-count basis, i.e., for cited articles with collaborating institutions from more than one country/economy, each country/economy receives fractional credit on basis of proportion of its participating institutions. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong. Other OECD excludes United States, Japan, and South Korea. Detail may not add to total because of rounding.

SOURCES: Thomson ISI, *SCI* and *SSCI*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-61.

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supporting knowledge-based industries closely linked to scientific research.

Growth in Patenting by Academic Institutions

Patenting by academic institutions increased markedly between 1988 and 2003, quadrupling from about 800 to more than 3,200 patents (appendix tables 5-67 and 5-68). (See also NSB 1996, appendix table 5-42.) The academic share of patents also rose slightly during this period, even as growth in all U.S. patents increased rapidly (figure 5-59).

Several factors appear to have supported the rapid rise in academic patenting:

♦ **The Bayh-Dole University and Small Business Patent Act.** This 1980 law (Public Law 96-517) established a uniform government-wide policy and process for government grantees and contractors to retain title to inventions resulting from federally supported R&D (whether fully

Table 5-24
Worldwide citations of U.S. scientific articles, by field: Selected years, 1992–2003

Field	1992	1995	1997	1999	2001	2003
All fields	1,389,314	1,593,418	1,648,899	1,696,859	1,678,294	1,839,481
Clinical medicine	475,793	538,931	574,859	584,330	589,762	649,522
Biomedical research	460,148	553,775	572,122	594,596	568,328	596,642
Biology	52,535	58,998	58,130	56,981	57,899	71,664
Chemistry	88,010	105,770	105,762	110,927	109,703	136,724
Physics	137,922	139,810	131,958	125,968	120,593	112,046
Earth/space sciences	55,086	69,487	73,507	83,053	82,614	100,282
Engineering/technology	32,680	34,631	32,958	34,001	36,809	45,178
Mathematics	6,858	6,492	6,418	7,520	7,794	9,504
Social/behavioral sciences	80,282	85,524	93,187	99,481	104,793	117,919

NOTES: Citations on fractional-count basis, i.e., for cited articles with collaborating institutions from outside the United States, the United States receives fractional credit on basis of proportion of its participating institutions. Social/behavioral sciences consist of psychology, social sciences, health sciences, and professional fields. Engineering/technology includes computer sciences. Biology includes agricultural sciences. Detail may not add to total because of rounding.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-61.

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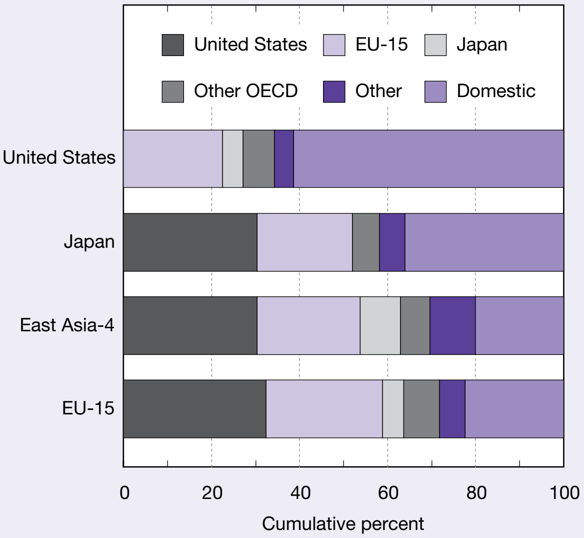
Figure 5-56
Citation of S&E literature, by major S&E publishing region or country/economy: 2003



EU = European Union; OECD = Organisation for Economic Co-operation and Development

NOTES: Citations on fractional-count basis, i.e., for cited articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. EU citation of EU literature consists of citation of EU member countries outside of each member country. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong. Other OECD excludes United States, Japan, and South Korea.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Table 5-25
Relative prominence of citations of scientific literature, by major S&E publishing region or country/economy: 1992, 1997, and 2003
(Relative citation index)

Region or country/economy	1992	1997	2003
United States	1.000	1.016	1.026
EU-15	0.659	0.689	0.737
Japan	0.566	0.539	0.575
East Asia-4	0.255	0.275	0.335

EU = European Union

NOTES: Relative citation index is major publishing region/country/economy's share of cited literature adjusted for its share of published literature. Citations of country/economy's own literature are excluded. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *Science Citation Index* and *Social Sciences Citation Index*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-62.

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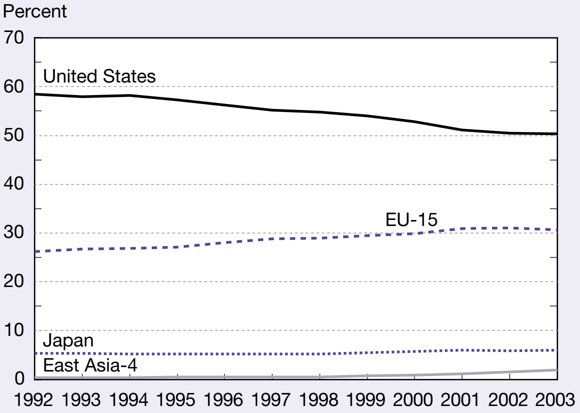
or partially funded) and encouraged the licensing of such inventions to industry.

- **Emerging and maturing research-based industries.** During the 1990s, industries emerged and matured that used commercial applications derived from "use-oriented" basic research in life sciences fields such as molecular biology and genomics (Stokes 1997).
- **Strengthening of patent protection.** Changes in the U.S. patent regime strengthened overall patent and copyright protection and encouraged the patenting of biomedical and life sciences technology. The creation of the Court of Appeals of the Federal Circuit to handle patent infringement cases was one factor in the strengthening of overall patent protection. The Supreme Court's landmark 1980

Figure 5-57
Share of top 5% of cited S&E articles, by major S&E publishing region or country/economy: 1992–2003



EU = European Union

NOTES: Citations are references to scientific articles in journals covered by *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI).* Citation counts based on a 3-year period with 2-year lag (e.g., citations for 2003 are references made in articles published in 2003 to top 5% of articles published in 1999–2001). Citations on fractional-count basis, i.e., for cited articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions. East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *SCI* and *SSCI,* http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-63.

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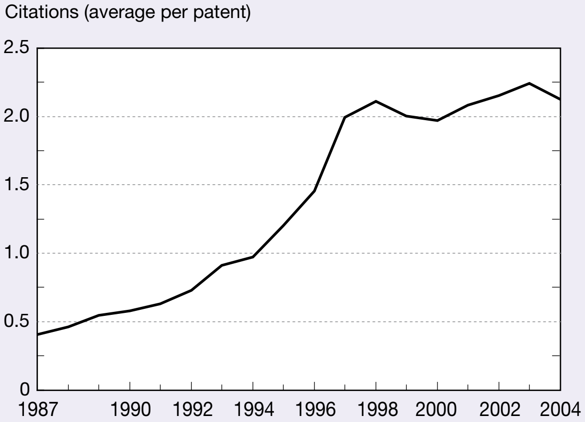
ruling in *Diamond* v. *Chakrabarty,* which allowed patentability of genetically modified life forms, also may have been a major stimulus behind the recent rapid increases.

Figure 5-58
Citations of S&E material in U.S. patents: 1987–2004



NOTE: S&E material constitutes references to articles in S&E journals and nonarticle materials such as reports, technical notes, and conference proceedings.

SOURCES: ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations. See appendix table 5-65.

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The rise in U.S. academic patenting has been accompanied by a growing number of patents awarded to institutions. The number of institutions awarded patents increased by more than 60% between the late 1980s and 2003 to 198 (appendix tables 5-67 and 5-68).[51] Both public and private institutions participated in this rise. Despite the increase in institutions receiving patents, the distribution of patenting activity has remained highly concentrated among a few major research universities. Among the top 100 R&D institutions, the top 25 recipients between 1994 and 2003 accounted for 55% of all academic patents in 2003, a share that has remained

Table 5-26
Share of U.S. patents citing S&E literature, by nationality of inventor: 1990, 1997, and 2003
(Percent distribution)

	1990		1997		2003	
Nationality of inventor	Total (90,379)	Citing literature (6,367)	Total (112,030)	Citing literature (15,423)	Total (164,450)	Citing literature (20,111)
Worldwide	100.0	100.0	100.0	100.0	100.0	100.0
United States	52.4	63.1	54.9	66.8	51.1	64.5
EU-15	19.5	16.5	15.7	14.8	15.1	15.0
Japan	21.6	15.2	20.7	12.0	21.6	11.2
East Asia-4	1.2	0.3	3.8	1.2	7.0	2.4
All other countries	5.3	4.9	4.9	5.2	5.2	6.9

EU = European Union

NOTES: Number of U.S. patents (in parentheses) and nationality of inventor based on U.S. patents referencing S&E articles in journals classified and tracked by *Science Citation Index (SCI).* East Asia-4 consists of China, Singapore, South Korea, and Taiwan. China includes Hong Kong.

SOURCES: Thomson ISI, *SCI*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Table 5-27
Citation of S&E literature in U.S. patents relative to share of scientific literature, by selected major publishing region or country/economy and field: 2004
(Relative citation index)

Field	United States	European Union-15	Japan	East Asia-4
All fields	1.208	0.784	0.851	0.578
Clinical medicine	1.102	0.816	0.716	0.424
Biomedical research	1.242	0.744	0.590	0.363
Chemistry	2.128	1.619	1.326	0.906
Physics	1.249	0.603	1.333	0.873
Engineering/technology	1.158	0.791	0.993	0.590

NOTES: Relative citation index is frequency of citation of major publishing region/country/economy's scientific literature by U.S. patents, adjusted for its world share of published S&E literature. Citations of country/economy's own literature are excluded. Index of 1.00 indicates region/country/economy's share of cited literature equals its world share of scientific literature. Index >1.00 or <1.00 indicates region cited relatively more/less frequently than indicated by its share of world S&E literature. Citations are references to U.S. S&E articles in journals indexed and tracked by *Science Citation Index (SCI)* and *Social Sciences Citation Index (SSCI)*. Citation counts based on 6-year window with 2-year lag, (e.g., citations for 2002 are references in U.S. patents issued in 2002 to articles published in 1995–2000). Scientific field determined by ipIQ's classification of journal. Engineering/technology includes computer sciences.

SOURCES: Thomson ISI, *SCI* and *SSCI*, http://www.isinet.com/products/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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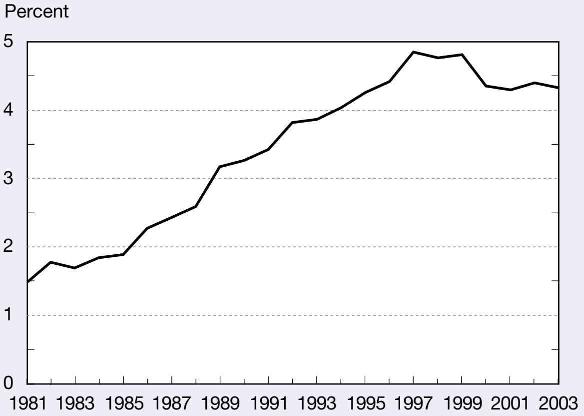
constant for two decades. Including the next 75 largest recipients increases the share to more than 80% of patents granted to all institutions since 1987 (appendix tables 5-67 and 5-68).

The growth in academic patents occurred primarily in the life sciences and biotechnology (Huttner 1999). Patents in two technology areas or *utility classes,* both with presumed biomedical relevance, accounted for a third of the academic total in 2003, up from less than a fourth in the early 1980s. The class that experienced the fastest growth, class 435 (chemistry, molecular biology, and microbiology), doubled its share during this period (figure 5-60). Its share, however, fell from a peak of 21% in 1998 to 15% in 2003.

Figure 5-59
U.S. academic share of patenting by U.S. private and nonprofit sectors: 1981–2003



NOTES: Patents issued by U.S. Patent and Trademark Office (U.S. PTO) to U.S. universities and corporations. U.S. private and nonprofit sectors include U.S. corporations (issued bulk of patents in this category), nonprofits, small businesses, and educational institutions.

SOURCES: U.S. PTO, *Technology Assessment and Forecast Report: U.S. Colleges and Universities, Utility Patent Grants, 1969–2003* (2004); and special tabulations.

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A survey by the Association of University Technology Managers (AUTM), which tracks several indicators of academic patenting, licensing, and related practices, shows the expansion of patenting and related activities by universities (table 5-28; appendix table 5-69). The number of new patent applications more than quintupled between FY 1991 and FY 2003,[52] indicating the growing effort and increasing success of universities obtaining patent protection for their technology.

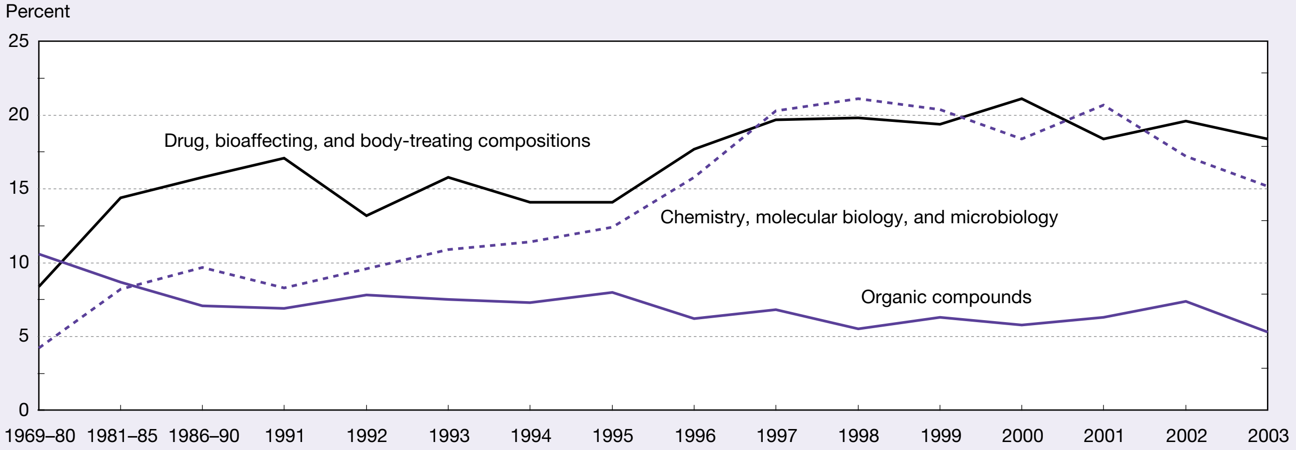
Invention Disclosures and Licensing Options

Two indicators related to patents, invention disclosures and new licenses and options, provide a broader picture of university efforts to exploit their technology. *Invention disclosures,* which describe the prospective invention and are submitted before a patent application or negotiation of a licensing agreement, rose sharply during this period. *New licenses and options,* indicating the commercialization of university-developed technology, grew by more than 40% between FY 1997 and FY 2003 (table 5-28; appendix table 5-69).

The majority of licenses and options are executed with small companies, either existing or startups (figure 5-61). In cases of unproven or very risky technology, universities often opt to make an arrangement with a startup company because existing companies may be unwilling to take on the risk. Faculty involvement in startups may also play a key role in this form of alliance. The majority of licenses granted to startups are exclusive, which do not allow the technology to be commercialized by other companies.

With the continuing increase of revenue-generating licenses and options, income to universities from patenting and licenses grew substantially during the 1990s and the early part of this decade, reaching more than $850 million in FY 2003, more than twice as much as the FY 1997

Figure 5-60
Academic patents in three largest utility classes: 1969–2003



SOURCES: U.S. Patent and Trademark Office, T*echnology Assessment and Forecast Report: U.S. Colleges and Universities, Utility Patent Grants, 1969–2002* (2001); and National Science Foundation, Division of Science Resources Statistics, special tabulations.

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Table 5-28
Academic patenting and licensing activities: Selected years, 1991–2003

Activity indicator	1991 (98)	1993 (117)	1995 (127)	1997 (132)	1999 (139)	2001 (139)	2003 (165)
				Millions of dollars			
Net royalties	NA	195.0	239.1	391.1	583.0	753.9	866.8
Gross royalties	130.0	242.3	299.1	482.8	675.5	868.3	1,033.6
Royalties paid to others	NA	19.5	25.6	36.2	34.5	41.0	65.5
Unreimbursed legal fees expended	19.3	27.8	34.4	55.5	58.0	73.4	101.3
New research funding from licenses[a]	NA	NA	112.5	136.2	149.0	225.7	212.8
				Number			
Invention disclosures received	4,880	6,598	7,427	9,051	10,052	11,259	13,718
New U.S. patent applications filed	1,335	1,993	2,373	3,644	4,871	5,784	7,203
U.S. patents granted	NA	1,307	1,550	2,239	3,079	3,179	3,450
Startup companies formed	NA	NA	169	258	275	402	348
Revenue-generating licenses/options	2,210	3,413	4,272	5,659	6,663	7,715	11,118
New licenses/options executed	1,079	1,737	2,142	2,707	3,295	3,300	3,855
Equity licenses/options	NA	NA	99	203	181	328	316
				Percent[b]			
Sponsored research funds	65	75	78	82	82	84	87
Federal research funds	79	85	85	90	90	92	94

NA = not available

[a] Directly related to license or option agreement.

[b] Of national academic total represented by number of institutions reporting.

NOTES: Number of institutions reporting given in parentheses. See appendix table 5-55.

SOURCE: Association of University Technology Managers, *AUTM Licensing Survey* (various years). See appendix table 5-69.

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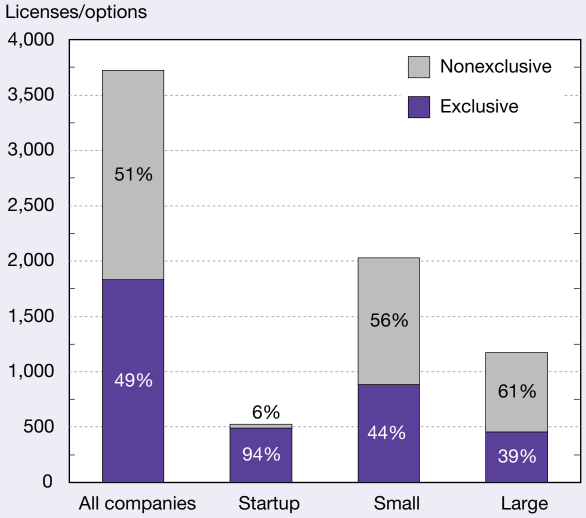
level.[53] Licensing income, however, is only a small fraction of overall academic research spending, amounting to less than 3% in FY 2003.[54] Licensing income is highly concentrated among a few universities and blockbuster patents. Of the institutions reporting data on royalties from patenting and licensing in FY 2003, less than 10% received $25 million or more in gross income, whereas more than half received less than $1 million (table 5-29).

Because licensing income has been highly concentrated among relatively few universities, technology transfer has not been financially lucrative for most universities (Powers 2003).[55] Universities are motivated by factors other than profitability, such as signaling the technological capability of their research, encouraging collaboration with industry, and helping their professors disseminate their research for commercialization.[56]

Because university-industry collaboration and successful commercialization of academic research in the United States contributed to the rapid transformation of new and often basic knowledge into industrial innovations, other nations are trying to strengthen innovation by adopting similar practices. (See sidebar, "Academic Patenting and Licensing in Other Countries".)

Figure 5-61
Characteristics of licenses and options executed by U.S. universities: 2003



NOTES: Exclusive agreements do not allow sharing or marketing of technology to other companies, whereas this is permitted under nonexclusive agreements. Numbers in bars are percent share of exclusive and nonexclusive licenses of each type of company. Large companies are firms with >500 employees when license/option was signed. Small companies are firms with <500 employees when license/option was signed. Start-up companies are companies that were dependent on licensing of academic institution's technology for initiation.

SOURCE: Association of University Technology Managers, *AUTM Licensing Survey: FY 2003* (2004).

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Table 5-29
University income from patenting and licensing activities, by income level: 2003

Gross income ($ millions)	Number of institutions
>50.00	3
25.00–50.00	7
10.00–24.99	13
5.00–9.99	12
1.00–4.99	38
<1.00	81

NOTE: Income excludes income paid to other institutions.

SOURCE: Association of University Technology Managers, *AUTM Licensing Survey: FY 2003* (2004).

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Academic Patenting and Licensing in Other Countries

Beginning in the mid-1990s, several countries, particularly members of the Organisation for Economic Co-operation and Development (OECD), sought to encourage and increase commercialization of technology developed at universities and other publicly supported research institutions (table 5-30). The focus has been on clarifying and strengthening ownerships and exploitation of an institution's intellectual property and on granting ownership of intellectual property to universities and other public research organizations in countries where the inventor or government was the owner. The justification for these legal and policy changes is that institutional ownership provides greater legal certainty, lowers transaction costs, and fosters more formal and efficient channels for technology transfer as compared with ownership by the government or the inventor (OECD 2002). Changes in intellectual property protection of academic institutions were through a variety of means, including reforming national patent policies, employment law, and research funding regulation and clarifying policy and administrative procedures of technology license offices.

The motivation for consideration and change of these countries' regulations and policies is due to a variety of factors (OECD 2002; Mowery and Sampat 2002):

- **Emulation of the United States.** Many countries believe that the United States has been very successful at commercializing its university technology, especially following the passage of the Bayh-Dole Act, which they consider a key factor in allowing the United States to benefit economically from its scientific research through encouraging and speeding up the commercialization of university inventions. This is especially true of European countries that would like to create indigenous science-based industries and believe that the level of commercialization from their public research and development is inadequate.
- **Exploitation of inventions developed from publicly funded research.** There is concern that current regulations and practices limit and slow the commercialization of technology developed from publicly funded research. Countries would like a greater commercial return from their investments in public scientific

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research and believe that strengthening and clarifying policies toward licensing and patenting will encourage and speed up commercialization.

- **Generation of licensing revenues.** Countries believe an increase in patenting and licensing by universities will increase revenue from licensing technology, which could support university technology activities or university research. Some countries, however, acknowledged that licensing offices lose money on their operations and are considering subsidizing their operations with public funding.
- **Formation of spinoff companies.** Countries believe that commercialization of university-developed technology could yield formation of startup companies. Forming spinoff companies is viewed as desirable for creating new high-technology or science-based jobs and industries, fostering entrepreneurial skills and culture, and increasing competition among existing firms.
- **Promotion of international scientific collaboration.** The European Union (EU)-15 countries, in particular, are concerned that differing national laws and policies, particularly with regard to ownership of university technology, inhibit scientific collaboration within the EU by raising transaction costs due to legal complications and uncertainty.

The OECD conducted a survey in 2001 of member countries' technology transfer offices and examined national laws and regulations. The survey found that in countries that enacted legislation, awareness of and support for technology transfer increased among the major stakeholders, although relatively little growth in patenting, licensing, or spinoffs occurred. In addition, most licensing of technology from universities and public research organizations does not originate from patentable inventions. These findings raise the question of whether specific features of the U.S. education, research, and legal systems play a key part in the commercialization of the results of academic R&D in the United States.

Table 5-30
Ownership of academic intellectual property in OECD countries: 2003

Country	Owner of invention: University	Owner of invention: Faculty	Owner of invention: Government	Status/recent initiatives
Australia	x	na	na	
Austria	x	na	na	
Belgium	x	na	na	
Canada[a]	x	x	na	
Denmark	x	na	na	
Finland	na	x	na	Consideration of legislation in 2003 to restrict faculty's right to retain ownership of publicly funded research.
France	x	na	na	
Germany	x	na	na	Debate during 2001 over awarding ownership to universities.
Iceland	na	x	na	
Ireland	x	na	na	
Italy	na	x	na	Legislation passed in 2001 to give ownership rights to researchers. Legislation introduced in 2002 to grant ownership to universities and create technology transfer offices.
Japan[b]	na	x	o	Private technology transfer offices authorized in 1998.
Mexico	x	na	na	
Netherlands	x	na	na	
Norway	na	x	na	Legislation passed in 2003 to allow universities to retain ownership of publicly funded research.
Poland	x	na	na	
South Korea	x	na	na	
Sweden	na	x	na	Recent debate and consideration of legislation to allow universities to retain ownership of publicly funded research.
United Kingdom	x	o	na	Universities, rather than government, given rights to faculty inventions in 1985.
United States[c]	x	o	o	

x = legal basis or most common practice; na = not applicable; o = allowed by law/rule but less common
OECD = Organisation for Economic Co-operation and Development

[a] Ownership of intellectual property funded by institutional funds varies, but publicly funded intellectual property belongs to institution performing research.
[b] President of national university or interuniversity institution determines right to ownership of invention by faculty member, based on discussions by invention committee.
[c] Universities have first right to elect title to inventions resulting from federally funded research. Federal government may claim title if university does not. In certain cases, inventor may retain rights with agreement of university/federal partner and government.

SOURCES: OECD, *Questionnaire on the Patenting and Licensing Activities of PROs* (2002); and D.C. Mowery and B.N. Sampat, International emulation of Bayh-Dole: Rash or rational? Paper presented at American Association for the Advancement of Science symposium on International Trends in the Transfer of Academic Research (February 2002).

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Conclusion

Strengths combined with emerging challenges characterize the position of academic R&D in the United States during the first decade of the 21st century. U.S. universities and colleges continued to be an important participant in the U.S. R&D enterprise, performing nearly half the basic research nationwide and having a significant presence in applied research. Funding of academic R&D continues to expand. The size of both the overall academic S&E doctoral workforce and the academic research workforce continues to increase. Citation data indicate that U.S. scientific publications remain influential relative to those of other countries. However, the volume of U.S. article output has not kept up either with the increases in academic R&D funding and research personnel or with the increasing outputs of the EU-15 and several East Asian countries. In fact, the number of U.S. articles published in the world's leading S&E journals has essentially been level since the early to mid-1990s, a trend that remains unexplained.

Although funding for academic R&D has been increasing, a number of shifts in funding sources have occurred, the long-term implications of which are uncertain. After declining for many years in relative share, although not in absolute dollars, the federal government's role in funding academic R&D has begun to increase. Research-performing universities have also increased the amount of their own funds devoted to research. Industry support for academic R&D, after growing faster than any other source of support through the turn of the century, declined in real absolute dollars for 3 successive years. The share of state and local support for academic R&D reached an all-time low in 2003.

The structure and organization of the academic R&D enterprise have also changed. Research-performing colleges and universities continue to expand their stock of research space and are investing substantially greater amounts in constructing research space than in previous years. However, spending on research equipment as a share of all R&D expenditures declined to an all-time low of 4.5% by 2003. With regard to personnel, a researcher pool has grown, independent of growth in the faculty ranks, as academic employment continued a long-term shift toward greater use of nonfaculty appointments. The shift has been marked by a substantial increase in the number of postdocs over a long period, although the number began to decline during the past several years. These changes have occurred during a period in which both the median age of the academic workforce and the percentage of that workforce age 65 or older have been rising.

A demographic shift in academic employment has also been occurring, with increases in the shares of women, Asians/Pacific Islanders, and underrepresented minorities. This shift is expected to continue into the future. Among degree holders who are U.S. citizens, white males were earning a decreasing number of S&E doctorates. On the other hand, the number of S&E doctorates earned by U.S. women and members of minority groups has been increasing, and these new doctorate holders were more likely to enter academia than white males. A more demographically diverse faculty, by offering more varied role models, may attract students from a broader range of backgrounds to S&E careers.

The academic R&D enterprise is also becoming more globalized in a number of ways. U.S. academic scientists and engineers are collaborating extensively with international colleagues: in 2003, one U.S. journal article in four had at least one international coauthor. The intimate linkage between research and U.S. graduate education, regarded as a model by other countries, helps to lure large numbers of foreign students to the United States, many of whom stay after graduation. Academia has also been able to attract many talented foreign-born scientists and engineers into its workforce, with the percentage of foreign-born degree holders approaching half the total in some fields. However, tighter visa and immigration restrictions instituted after the terrorist attacks of September 11, 2001, may have complicated the prospects for current and future foreign students and scientists living in the United States.

Intersectoral collaboration within the United States is also increasing, particularly between universities and industry. Academic articles are increasingly cited in U.S. patents, attesting to the usefulness of academic research in producing economic benefits. Academic patenting and licensing continue to increase. Academic licensing and option revenues are growing, as are spinoff companies, and universities are increasingly moving into equity positions to maximize their economic returns. As a result, questions have arisen about the changing nature of academic research, the uses of its results, and the broader implications of closer ties between academia and industry.

Notes

1. Federally funded research and development centers (FFRDCs) associated with universities are tallied separately and are examined in greater detail in chapter 4. FFRDCs and other national laboratories (including federal intramural laboratories) also play an important role in academic research and education, providing research opportunities for both students and faculty at academic institutions.

2. For this discussion, an academic institution is generally defined as an institution that has a doctoral program in science or engineering, is a historically black college or university that expends any amount of separately budgeted R&D in S&E, or is some other institution that spends at least $150,000 for separately budgeted R&D in S&E.

3. Despite this delineation, the term "R&D" (rather than just "research") is primarily used throughout this discussion because data collected on academic R&D do not always differentiate between research and development. Moreover, it is often difficult to make clear distinctions among basic research, applied research, and development.

4. The academic R&D funding reported here includes only separately budgeted R&D and institutions' estimates

of unreimbursed indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing.

5. This follows a standard of reporting that assigns funds to the entity that determines how they are to be used rather than to the one that necessarily disburses the funds.

6. The medical sciences include fields such as pharmacy, veterinary medicine, anesthesiology, and pediatrics. The biological sciences include fields such as microbiology, genetics, biometrics, and ecology. These distinctions may be blurred at times because boundaries between fields often are not well defined.

7. In this chapter, the broad S&E fields refer to the physical sciences; mathematics; computer sciences; the earth, atmospheric, and ocean sciences; the life sciences; psychology; the social sciences; other sciences (those not elsewhere classified); and engineering. The more disaggregated S&E fields are referred to as "subfields."

8. The recent creation of the Department of Homeland Security (DHS) should have major implications for the future distribution of federal R&D funds, including federal academic R&D support, among the major R&D funding agencies. DHS's Directorate of Science and Technology is tasked with researching and organizing the scientific, engineering, and technological resources of the United States and leveraging these existing resources into technological tools to help protect the homeland. Universities, the private sector, and the federal laboratories are expected to be important DHS partners in this endeavor.

9. Another hypothesis is that some of the difference may be due to many public universities not having the incentive to negotiate full recovery of indirect costs of research because the funds are frequently captured by state governments.

10. The Carnegie Foundation for the Advancement of Teaching classified about 3,600 degree-granting institutions as higher education institutions in 1994. See chapter 2 sidebar, "Carnegie Classification of Academic Institutions," for a brief description of the Carnegie categories. These higher education institutions include 4-year colleges and universities, 2-year community and junior colleges, and specialized schools such as medical and law schools. Not included in this classification scheme are more than 7,000 other postsecondary institutions such as secretarial schools and auto repair schools.

11. Inflation averaged less than 2% over the period discussed. For an analysis of this trend among the top 200 institutions with the largest R&D expenditures and for a comparison of institutions that increased their R&D expenditures by more than 3% over the preceding year with those that did not, see NSF/SRS 2004.

12. Although the number of institutions receiving federal R&D support between 1973 and 1994 increased overall, a rather large decline occurred in the early 1980s, most likely due to the fall in federal R&D funding for the social sciences during that period.

13. Research-performing academic institutions are defined as colleges and universities that grant degrees in science or engineering and expend at least $1 million in R&D funds. Each institution's R&D expenditure is determined through the NSF Survey of Research and Development Expenditures at Universities and Colleges.

14. Research space here is defined as the space used for sponsored research and development activities at academic institutions that is separately budgeted and accounted for. Research space is measured in NASF, the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside faces of walls. Multipurpose space that is at least partially used for research is prorated to reflect the proportion of time and use devoted to research.

15. Some of this space will likely replace existing space and therefore will not be a net addition to existing stock.

16. Institutional funds may include operating funds, endowments, tax-exempt bonds and other debt financing, indirect costs recovered from federal grants/contracts, and private donations.

17. Institutions rated space using four categories: (1) space in superior condition that is suitable for the most scientifically competitive research in the field over the next 2 years; (2) space in satisfactory condition that is suitable for continued use over the next 2 years for most levels of research in the field but that may require minor repairs or renovation; (3) space that requires renovation and that will no longer be suitable for current research without undergoing major renovation with the next 2 years; and (4) space that requires replacement and that should stop being used for current research within the next 2 years.

18. The "bricks and mortar" section of the Survey of Science and Engineering Research Facilities asked institutions to report on their research space only. The reported figures therefore do not include space used for other purposes such as instruction or administration. In the networking and computing section of the survey, however, respondents were asked to identify all of their computing and networking resources, regardless of whether these resources were used for research.

19. Innovation is the generation of new or improved products, processes, and services. For more information, see chapter 6.

20. This set of institutions constitutes the Carnegie Research I and II institutions, based on the 1994 classification. These institutions have a full range of baccalaureate programs, have a commitment to graduate education through the doctorate, award at least 50 doctoral degrees annually, and receive federal support of at least $15.5 million (1989–91 average); see Carnegie Foundation for the Advancement of Teaching (1994). The other Carnegie categories include doctorate-granting institutions, master's (comprehensive) universities and colleges; baccalaureate (liberal arts) colleges; 2-year community and junior colleges; and specialized schools such as engineering and technology, business

and management, and medical and law schools. The classification has since been modified, but the older schema is more appropriate to the discussion presented here.

21. The academic doctoral S&E workforce includes those with a doctorate in an S&E field in the following positions: full and associate professors (referred to as *senior faculty*); assistant professors and instructors (referred to as *junior faculty*); postdocs; other full-time positions such as lecturers, adjunct faculty, research and teaching associates, and administrators; and part-time positions of all kinds. Unless specifically noted, data on S&E doctorate holders refer to persons with an S&E doctorate from a U.S. institution, as surveyed biennially by NSF in the Survey of Doctorate Recipients. All numbers are estimates rounded to the nearest 100. The reader is cautioned that small estimates may be unreliable.

22. It is impossible to establish causal connections among these developments with the data at hand.

23. For more information on this subject, see the discussion of postdocs in chapter 3.

24. See also the discussion of retirements from the S&E workforce in chapter 3.

25. A 1986 amendment to the Age Discrimination in Employment Act of 1967 (Public Law 90-202) prohibited mandatory retirement on the basis of age for almost all workers. Higher education institutions were granted an exemption through 1993 that allowed termination of employees with unlimited tenure who had reached age 70.

26. For more information about the effects of mentoring, see *Diversity Works: The Emerging Picture of How Students Benefit* (Smith et al. 1997).

27. See chapter 2, "Doctoral Degrees by Sex."

28. See chapter 2, "S&E Bachelor's Degrees by Race/Ethnicity."

29. Both the number and share of Asian/Pacific Islander S&E doctorate recipients employed in academia are probably larger than is reported here because those who received S&E doctorates from universities outside the United States are not included in the analysis.

30. In 2003, 58% of those who were foreign born were U.S. citizens.

31. For a more thorough discussion of the role of foreign scientists and engineers, including the possible impact of security policies set in place after September 11, 2001, see chapters 2 and 3.

32. Public service includes activities established primarily to provide noninstructional services beneficial to individuals and groups external to the institution. These activities include community service programs and cooperative extension services.

33. The survey question on which this analysis is based encompasses four separate items that are considered to be academic research: basic research, applied research, development, and design. In the following discussion, unless specifically stated otherwise, the term *research* refers to all four.

34. For technical reasons, the postdoc number excludes holders of S&E doctorates awarded by foreign universities. Data from NSF's Survey of Graduate Students and Postdoctorates in Science and Engineering suggest that in 2003, the number of postdocs in U.S. academic institutions with doctorates from foreign institutions was approximately twice that of those with U.S. doctorates. Most of them could be expected to have research as their primary work activity.

35. For a more detailed treatment of graduate education in general, including the mix of graduate support mechanisms and sources, see chapter 2.

36. This measure was constructed slightly differently in the 1980s and in the 1990s, starting in 1993, and is not strictly comparable across these periods. Therefore, the crossing over of the two trends in the 1990s could reflect only a methodological difference. However, the very robust trend in the life sciences, in which researchers started outnumbering teachers much earlier, suggests that this methodological artifact cannot fully explain the observed trend. Individuals can be counted in both groups.

37. The field of computer sciences, in which scientists disseminate much of their research through peer-reviewed conference proceedings, is one exception.

38. The EU-15 are the 15 EU countries before the expansion of EU membership on May 1, 2004: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

39. Changes over time in journal coverage could distort U.S. output for reasons that have little or nothing to do with publishing intensity, such as coverage of new non-English journals. To control for changes in *SCI/SSCI* journal coverage that may have occurred for these extraneous reasons, we also performed analyses on a fixed set of journals indexed in 1985. These analyses found the U.S. trend relative to other publishing centers to be accentuated, with U.S. output falling 10% between 1992 and 2003, whereas output grew in the EU-15, Japan, and the East Asia-4.

40. The social and behavioral sciences consist of psychology, the social sciences, the health sciences, and professional fields.

41. International articles may also have multiple U.S. addresses.

42. A moderately high correlation ($r^2 = 0.66$) exists between the number of U.S. doctorates awarded to foreign-born students, by country, in 1994–98 and the volume of papers coauthored by the United States and those countries in 1997–2003.

43. Articles jointly authored exclusively between or among the economies of the East Asia-4 are not counted as international articles.

44. Citations are not a straightforward measure of quality, for the following reasons: authors' citation of their own previous articles; authors' citation of the work of colleagues, mentors, and friends; and a possible nonlinear relationship between a country's output of publications and citations to that output.

45. The relative citation index is the share of a region or country's S&E literature cited by the rest of world adjusted

for its share of published S&E literature. A region or country's citations of its own literature are excluded from the relative citation index to remove the potential bias of authors citing their own research, institutions, or national literature.

46. The U.S. PTO evaluates patent applications on the basis of whether the invention is useful, novel, and nonobvious. The novelty requirement leads to references to other patents, scientific journal articles, meetings, books, industrial standards, technical disclosures, etc. These references are termed *prior art.*

47. Citation data must be interpreted with caution. The use of patenting varies by type of industry, and many citations in patent applications are to prior patents. Patenting is only one way that firms seek returns from innovation and thus reflects, in part, strategic and tactical decisions (e.g., laying the groundwork for cross-licensing arrangements). Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more products in the future. (See Geisler 2001.)

48. Citations are references to S&E articles in journals indexed and tracked by the *Science Citation Index* and *Social Sciences Citation Index*. Citation counts are based on articles published within a 12-year period that lagged 3 years behind the issuance of the patent. For example, citations for 2000 are references made in U.S. patents issued in 2000 to articles published in 1986–97.

49. Research articles also are increasingly cited in patents, attesting to the close relationship of some basic academic research to potential commercial applications. See the previous section, "Citations in U.S. Patents to S&E Literature."

50. Other means of technology transfer are industry hiring of students and faculty, consulting relationships between faculty and industries, formation of firms by students or faculty, scientific publications, presentations at conferences, and informal communications between industrial and academic researchers.

51. The institution count is a conservative estimate because several university systems are counted as one institution, medical schools are often counted with their home institution, and universities are credited for patents on the basis of being the first-name assignee on the patent, which excludes patents where they share credit with another first-name assignee. Varying and changing university practices in assigning patents, such as to boards of regents, individual campuses, or entities with or without affiliation to the university, also contribute to the lack of precision in the estimate. The data presented here have been aggregated consistently by the U.S. PTO since 1982.

52. Universities report data to AUTM on a fiscal-year basis, which varies across institutions.

53. Licensing income for 2000 was boosted by several one-time payments, including a $200 million settlement of a patent infringement case, and by several institutions' cashing in of their equity held in licensee companies.

54. See *Academic Research and Development Expenditures: Fiscal Year 2001* (NSF/SRS 2003). This is a rough estimate because of the lack of data on the R&D expenditures of a few smaller institutions.

55. Data on costs are not available, but can be considerable, such as patent and license management fees (Sampat 2002). Thursby and colleagues (2001) report that universities allocate an average of 40% of net income to inventors, 16% to the inventor's department or school (often returned to the inventor's laboratory), 26% to central administrations, and 11% to technology transfer offices, with the remainder allocated to "other."

56. Patenting by U.S. universities appears to have had no impact on publishing output, a concern voiced by some policymakers and researchers. S&E article output trends by top patenting universities between 1981 and 2001 were consistent with those of nonpatenting universities and the entire U.S. academic sector.

Glossary

Abilene: A high-performance network dedicated to research led by a consortium of universities, governments, and private industry; often called Internet2.

Academic institution: In the Financial Resources for Academic R&D section of this chapter, an institution that has a doctoral program in science or engineering, is a historically black college or university that expends any amount of separately budgeted R&D in S&E, or is some other institution that spends at least $150,000 for separately budgeted R&D in S&E. In the remaining sections, any accredited institution of higher education.

Cyberinfrastructure: Infrastructure based on distributed computer, information, and communication technology.

Federal obligations: Dollar amounts for orders placed, contracts and grants awarded, services received, and similar transactions during a given period, regardless of when funds were appropriated or payment was required.

Federally funded research and development center: R&D-performing organizations exclusively or substantially financed by the federal government either to meet particular R&D objectives or, in some instances, to provide major facilities at universities for research and associated training purposes; each FFRDC is administered either by an industrial firm, a university, or a nonprofit institution.

Innovation: Generation of new or improved products, processes, and services.

Intellectual property: Intangible property that is the result of creativity; the most common forms of intellectual property include patents, copyrights, trademarks, and trade secrets.

Net assignable square feet (NASF): The unit for measuring research space; NASF is the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for specific use, such as research or instruction.

Nontraditional student: One who does not move directly from high school to college; i.e., a transfer student, adult student, or part-time student.

Research space: the space used for sponsored R&D activities at academic institutions that is separately budgeted and accounted for.

Underrepresented minority: blacks, Hispanics, and American Indians/Alaska Natives are considered to be underrepresented in academic R&D.

References

American Association for the Advancement of Science (AAAS). 2004. R&D Earmarks Top $2 Billion in 2005. AAAS R&D Funding Update December 7, 2004. http://www.aaas.org/spp/rd/earm05c.pdf. Accessed June 2005.

Arunachalam S. 2002. Is science in India on the decline? *Current Science* 83(July 25):108–9.

Brainard J. 2002. Another record year for academic pork. *The Chronicle of Higher Education* 49(September 27).

Carnegie Foundation for the Advancement of Teaching. 1994. *A Classification of Institutions of Higher Education*. Princeton, NJ.

De Solla Price D. 1986. *Little Science, Big Science and Beyond*. New York: Columbia University Press.

European Commission. 2001. *A New Framework Programme for European Research—Towards a European Research Area*. Brussels, Belgium: European Union.

Geisler E. 2001. The mires of research evaluation. *The Scientist* 15(10):35. http://www.the-scientist.com/yr2001/may/opin_010514.html. Accessed July 2003.

Huttner S. 1999. Knowledge and the biotech economy: A case of mistaken identity. Paper presented at High-Level CERI/OECD/NSF Forum on Measuring Knowledge in Learning Economies and Societies; May; Arlington, VA.

Mowery DC, Sampat BN. 2002. International emulation of Bayh-Dole: Rash or rational? Paper presented at American Association for the Advancement of Science Symposium on International Trends in the Transfer of Academic Research; February; Boston.

National Research Council (NRC). 1991. *Ending Mandatory Retirement for Tenured Faculty*. Washington, DC: National Academy Press.

National Science Board (NSB). 1996. *Science and Engineering Indicators 1996.* NSB-96-21. Arlington, VA: National Science Foundation.

National Science Board (NSB). 2004. *Science and Engineering Indicators 2004*. NSB-04-1. Arlington, VA: National Science Foundation.

National Science Foundation (NSF). 2003. *Revolutionizing Science and Engineering Through Cyberinfrastructure: Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure*. Arlington, VA.

National Science Foundation, Division of Science Resources Statistics (NSF/SRS). 1995a. *Guide to NSF Science/Engineering Resources Data.* NSF 95-318. Arlington, VA.

National Science Foundation, Division of Science Resources Statistics (NSF/SRS). 1995b. *NSF Survey Instruments Used in Collecting Science and Engineering Resources Data.* NSF 95-317. Arlington, VA.

National Science Foundation, Division of Science Resources Statistics (NSF/SRS). 2000. *Latin America: R&D Spending Jumps in Brazil, Mexico, and Costa Rica.* NSF 00-316. Arlington, VA.

National Science Foundation, Division of Science Resources Statistics (NSF/SRS). 2003. *Academic Research and Development Expenditures: Fiscal Year 2001.* NSF 03-316. Arlington, VA.

National Science Foundation, Division of Science Resources Statistics (NSF/SRS). 2004. *U.S. Academic R&D Continues to Grow as More Universities and Colleges Expand Their R&D Activities*. NSF 04-319. Arlington, VA.

National Science Foundation, Division of Science Resources Statistics (NSF/SRS). Forthcoming. *Scientific and Engineering Research Facilities: 2003, Detailed Statistical Tables*. Arlington, VA.

Organisation for Economic Co-operation and Development (OECD). 2002. *OECD Questionnaire on the Patenting and Licensing Activities of PRO's*. Paris.

Powers J. 2003. Commercializing academic research. *The Journal of Higher Education* January/February:26–50.

Sampat B. 2002. Private parts: Patents and academic research in the twentieth century. Paper prepared for Research Symposium of the Next Generation of Leaders in Science and Technology Policy; 22–23 November; Washington, DC.

Smith DG, Gerbrick GL, Figueroa MA, Watkins GH, Levitan T, Moore LC, Merchant PA, Beliak HD, Figueroa B. 1997. *Diversity Works: The Emerging Picture of How Students Benefit.* Washington, DC: Association of American Colleges and Universities.

Stokes DE. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: Brookings Institution Press.

Thursby J, Jensen R, Thursby M. 2001. Objectives, characteristics and outcomes of university licensing: A survey of major U.S. universities. *Journal of Technology Transfer* 26:59–72.

Trune D, Goslin L. 2000. Assessment of technology transfer profitability within US universities. *European Biopharmaceutical Review* September:56–62.

U.S. Office of Management and Budget (OMB). 2004 Analytical perspectives. *Budget of the United States Government, Fiscal Year 2005.* Washington, DC.

U.S. Office of Management and Budget (OMB). 2005 Analytical perspectives. *Budget of the United States Government, Fiscal Year 2006.* Washington, DC.